LABORATORY DESIGN

Edited by **H. S. COLEMAN**

with an introduction by
ROLAND WANK

NATIONAL RESEARCH COUNCIL
REPORT ON DESIGN, CONSTRUCTION
AND EQUIPMENT OF LABORATORIES

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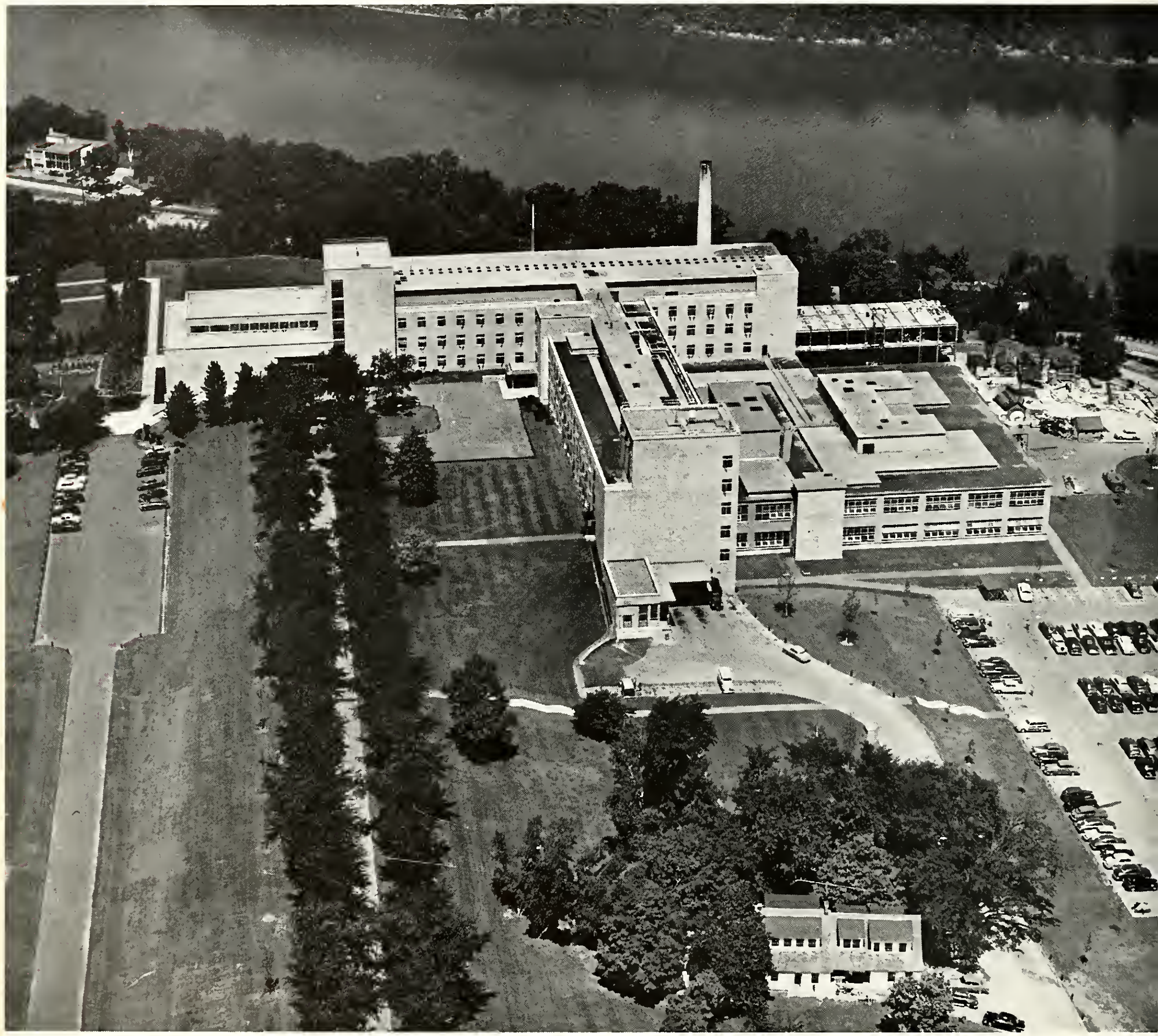

New General Electric Laboratory at Schenectady, N. Y. The main entrance is in the left wing of the building; left wing also houses the auditorium. The large two-story wing to the right contains the shops while the new office wing is under construction immediately behind this.

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PREFACE

- In a scientific research organization, facilities are second only to abilities. Notwithstanding this fact and notwithstanding the great growth of scientific research during the past two decades, there has been lacking a reference source of constructional information on laboratories. It is the aim of the present treatise to fill this gap in the literature by presenting authoritative up-to-date advice and essential data on the design, location, construction and equipment of laboratories for research and educational institutions and for the industries.

This book is intended to be especially helpful to laboratory directors and science teachers and to their architects and engineers, not only in planning and building but also in remodeling or enlarging their quarters. Its contents are concerned solely with *wh*ere scientific work can be done well, and are basically supplemental to *why*, *what* and *how* scientific activities such as research should be conducted. Within the past twenty years numerous institutional and company executives and scientists and also many architects have asked for such a book. We have tried to satisfy their needs as indicated by them and will be happy if they and others interested should find this contribution to be useful.

The wide studies outlined in the contents of this treatise were nurtured under the auspices of the National Research Council. A little history will give the origin and development of the field thus cultivated. A National Research Council Committee on the Construction and Equipment of Chemical Laboratories was formed in November, 1924. The members were G. L. Coyle, Chairman, Georgetown University; L. M. Dennis, Cornell University; C. R. Hoover, Wesleyan University; L. W. Mattern, McKinley High School, Washington, D. C.; and J. N. Swan, University of Mississippi. Appeals for help in the planning and building of laboratories soon came to the Committee in such numbers as to show a definite need for a ready, convenient and specialized reference work on the subject. The Committee therefore set to work to compile the information needed. Floor plans and specifications of recently constructed labora-

PREFACE

tories were requested and questionnaires were sent to more than a hundred colleges and universities as to the requisites for practical laboratory quarters. The responses constituted the basis of the report of the Committee which was published in 1930. The expense of preparing and issuing the report was underwritten by the Chemical Foundation, thus permitting the treatise to be offered to laboratory-planners at a nominal price. This publication dealt largely with teaching laboratories, although it contained an excellent chapter on "Industrial Chemical Laboratories" by A. V. H. Mory. The late J. N. Swan was a leader in the pioneer undertaking.

The Committee was re-appointed from year to year to serve as a source of dependable facts regarding problems in laboratory design and constructional materials. Owing, however, to the great shortage of building materials just before and during the years of World War II, laboratory construction practically ceased and the Committee was temporarily disbanded on May 11, 1943. On November 4, 1947, the Committee was re-activated as the "Committee on Design, Construction and Equipment of Laboratories" and specifically charged with the responsibility of preparing a new and fully modern report to replace the 1930 treatise, which had long been out of print. Members of the new Committee, named below, represent industrial and institutional research laboratories as well as teaching laboratories.

An effort has been made in the present book to indicate the constructional materials particularly adapted to laboratory buildings and to describe the types and arrangement of special facilities, services and equipment usually incorporated in such buildings. This wide discussion is followed by sections in which are set forth the problems confronting the planner of both teaching and industrial laboratory buildings, starting with the considerations underlying the selection of the site and including information on exterior construction, interior arrangement, special features of laboratories for specific purposes, and supplemental rooms, service departments and the like, which are essential in a modern laboratory building. Finally in Part IV are descriptions of a number of completed, functioning laboratory buildings of various types. Here is shown how the laboratory planner's problems have been solved in specific instances, and it is hoped that the methods followed may be of suggestive value. It must be borne in mind that the Committee's intent was to include only the problems peculiar to laboratory buildings. Consequently the book does not discuss such general subjects as heating, sanitary plumbing, ordinary ventilation and many others common to all buildings. For detailed information on the properties of chemical engineering materials of construction, the reader is referred to Ind. Eng. Chem. **42**, 2026-2076 (1950).

This treatise represents the ideas and experience of many specialists. There is, of course, some lack of unanimity regarding relatively minor points of design, but broadly there is complete agreement on the major features. Credit for the authorship of each section is noted and the Committee wishes to express here its sincere appreciation of the wholehearted cooperation given by all those who have contributed, either in the preparation of manuscripts or in giving wise counsel and constructive criticism. The entire work prior to its publication, was read critically by a number of authorities, embracing architects and building scientists, whose assistance is gratefully acknowledged.

The Chairman wishes to thank W. A. Hamor for his advice and encouragement which led to the chairman's undertaking the task and for his valuable suggestions in regard to the content and editing of the material submitted.

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TABLE OF CONTENTS

PREFACE iii

PART I. Materials, Facilities, Services and Equipment — General Discussion 2

1. Introduction 3
   Roland A. Wank, Architect, Fellheimer and Wagner, Architects
2. Interior Construction Materials 5
   Edward M. Jenkins, Section Chief, Wood Pulp Boards, Johns-Manville Research Center
3. Furniture 14
   Committee of Members of the Laboratory Equipment Section of the Scientific Apparatus Makers Association, J. A. Campbell, Chairman, Treasurer & General Sales Manager, Kewaunee Mfg. Co.
4. Plumbing 37
   John Edmund York, Building Service Engineer, Stone & Webster Engineering Corporation
5. Section 1. Laboratory Lighting 46
   J. L. Tugman, Engineering Publications, Engineering Division, Lamp Department, General Electric Co.
5. Section 2. Electric Power 58
   J. H. Eagen, Architect-Engineer, Hoffman & Crumpton, Architects
6. Laboratory Ventilation 61
   W. C. L. Hemeon, Senior Fellow, Multiple Fellowship of Industrial Hygiene Foundation, Mellon Institute
7. Safety Precautions 69
   Dr. F. A. Von Atta, Industrial Department, National Safety Council

PART II. Teaching Laboratories 74

1. Site Selection, Design and Construction 75
   Harry F. Lewis, Dean, The Institute of Paper Chemistry
2. Interior Arrangements 80
   Dr. C. S. Adams, Professor of Chemistry, Antioch College
3. The General Science Building 89
   Dr. W. A. Manuel, Head, Department of Chemistry, Ohio Wesleyan University
4. The General Chemistry Laboratory 95
   Dr. John C. Bailar, Jr., Professor of Chemistry, University of Illinois
5. The Analytical Chemistry Laboratory 100
   Dr. E. J. Meehan, Associate Professor of Physical Chemistry, Institute of Technology, University of Minnesota
6. The Organic Chemistry Laboratory 105
   Dr. Charles D. Hurd, Professor of Chemistry, Northwestern University

7. **The Physical and Electrochemical Laboratory . . . 109**
Dr. Lee O. Case, Assistant Professor of Physical Chemistry,
University of Michigan

8. **Biochemical and Related Laboratories 113**
Dr. A. A. Christman, Professor of Biological Chemistry,
Medical School, University of Michigan

9. **The Chemical Engineering Laboratory 122**
Dr. Charles C. Winding, Assistant Director,
College of Engineering, Cornell University

10. **The Metallographic Laboratory 134**
Dr. R. C. Ernst, Dean, and G. C. Williams, Head,
Department of Chemical Engineering,
Speed Scientific School, University of Louisville

PART III. Industrial Laboratories 138

1. **Location and General Design Features 139**

2. **Interior Arrangement 149**
Both chapters by Ralph T. Walker, Architect,
Voorhees, Walker, Foley & Smith, Architects

3. **Section 1. Analytical Control Laboratories: Examples of Laboratories 154**
Committee of the Scientific Apparatus Makers Association:
A. W. Fisher, President of the Fisher Scientific Company, Chairman

3. **Section 2. Details and Description of an Analytical Control Laboratory 182**
Dr. B. L. Clarke, Director, and A. S. Doniger, Assistant Director,
Chemical Control Division, and R. N. Boos, Head, Microanalytical
Laboratory, Research and Development Division, Merck & Co., Inc.

4. **Metallurgical Laboratories 191**
Dr. Harold K. Work, Director, Research Division,
New York University, College of Engineering

5. **Animal Rooms and Equipment 195**
Dr. Charles P. Carpenter, Senior Fellow, Multiple Fellowship on
Chemical Hygiene, Mellon Institute

6. **Industrial Laboratories for Physical Measurements . . 202**
Dr. Harold P. Klug, Head, Department of Research
in Chemical Physics, Mellon Institute

7. **The Design of Laboratories for the Safe Handling of Radioisotopes 214**
Myron B. Hawkins, U. S. Naval Radiological Defense Laboratory,
San Francisco Naval Shipyard

8. **Constant-Temperature-Humidity Rooms 228**
M. E. Dunlap, Engineer, Forest Products Laboratory
(maintained in cooperation with the University of Wisconsin),
Forest Service, U. S. Department of Agriculture

9. **High-Pressure Laboratories 241**
Dr. R. L. Savage, Associate Professor of Chemical Engineering,
Case Institute of Technology

10. **Laboratories for Electrochemistry 250**
Dr. K. G. Compton, Chemical Engineer, Bell Telephone
Laboratories, Inc., Murray Hill Laboratory

11. Auxiliary Facilities and Services 254
Gordon H. Stillson, Assistant Business Manager,
Gulf Research & Development Co.

12. Pilot Plant Laboratories 260
Dr. W. L. Faith, Director of Engineering, Chemical Division,
Corn Products Refining Co.

PART IV. Concise Descriptions of Some Modern Laboratories . . . 274

1. Illinois Institute of Technology Laboratory 275
Dr. Martin Kilpatrick, Chairman, Department of Chemistry,
Illinois Institute of Technology

2. Northwestern University Laboratory 280
V. C. Williams, Associate Director of Research,
General Aniline & Film Corp.

3. Reed College Laboratory 298
Dr. A. F. Scott, Professor of Chemistry,
Chemistry Department, Reed College

4. Drake University Laboratory 302
Dr. William H. Coppock, Acting Head, Department of Chemistry,
Drake University

5. Battelle Memorial Institute Research Buildings . . . 306
W. A. Welcker, Jr., In Charge of Building Maintenance and
Construction, Battelle Memorial Institute

6. Mellon Institute Research Laboratories 316
H. S. Coleman, Assistant Director, Mellon Institute

7. United States Department of Agriculture, Regional Research Laboratories 330
Dr. David J. Price, Collaborator, Bureau of Agricultural and
Industrial Chemistry, U. S. Department of Agriculture

8. Bell Telephone Laboratories 336
Charles S. Haines, Architect,
Voorhees, Walker, Foley & Smith, Architects

9. Johns-Manville Research Center 343
Edward M. Jenkins, Section Chief, Wood Pulp Boards,
Johns-Manville Research Center

10. Esso Research Center—Industrial Laboratory . . . 352
W. R. Hnot, Esso Engineering Department,
Standard Oil Development Company

11. B. F. Goodrich Research Center 364
D. H. Carnell, Manager, Engineering Service,
B. F. Goodrich Co. Research Center

12. Bureau of Mines Pilot Plant Laboratory 377
H. P. Greenwald, Regional Director, Region VIII, and
Earle P. Shaub, Chemical Engineer, Central Experimental Station,
Bureau of Mines, U. S. Department of Interior

13. University of Illinois, Pilot Plant Laboratory 383
Dr. H. F. Johnstone, Head, Department of Chemical Engineering,
University of Illinois

SELECTED BIBLIOGRAPHY 388

INDEX 391

LABORATORY DESIGN

Part I

MATERIALS, FACILITIES, SERVICES AND EQUIPMENT—GENERAL DISCUSSION

1

INTRODUCTION

Roland A. Wank

Fellheimer and Wagner, New York, N. Y.

There may have been a time when wars were won on the playing fields of Eton, but today survival itself depends on the work of laboratories—either in war or in the normal activities of industry and commerce. A prominent corporation executive once remarked to the writer that he felt his company was slipping in its rapidly changing field whenever the number of developments in the organization's laboratories, ready for full-scale production, fell below one hundred and twenty.

In recognition of their importance, laboratories have long since been moved from unused corners of factories into buildings of their own, which are often magnificent enough to function, on the side, as public relations showpieces.

Some of the best minds of the country have been responsible for this progress; research scientists, chemical engineers, plant managers, equipment manufacturers and others—ably assisted, and, as often as not, led and coordinated by architects.

It is interesting to compare the more or less casual references to the architect's function by chemists, engineers, school administrators and others who wrote most of the chapters of this book. (Four chapters have been written by architects.) The majority of the chapters undoubtedly reflect impressions derived from the writers' experiences with laboratory construction projects, though often it is not clear whether the writer was in close enough touch with the architect's work to be fully aware of its nature and significance.

Some of the chapters refer to the architect, together with the sponsor, the school board or the building committee, as a sort of esthetic law-enforcement agency interested primarily in the external appearance of the project, and its harmony with the rest of an ivy-covered or otherwise tradition-limited group of buildings. Others size him up as the man competent to design the structural frame, wall thicknesses, exit stairs and so forth in conformance with the building code. On the other hand, D. H. Cornell, in telling the story of the B. F. Goodrich Research Center, pays deliberate tribute to architect William M. Stanton for his vision, imagination and coordinating ability without which the knotty conflict between requirements and budget might never have been resolved. The sections written by the principals and staff of Voorhees, Walker, Foley & Smith—themselves among the outstanding architects of laboratories in the country—would certainly indicate their grasp of the whole range of problems from site selection to the last shutoff valve.

It might be trite, but certainly no more than fair, to assert that the architect preoccupied with appearance and devoted to straight-jacketing functional requirements into a Gothic or Renaissance shell has become rare to the point of extinction—if, indeed, he ever existed in any number.

Quite the contrary, architects are apt to possess the same turn of mind as research scientists—forever trying to roll back the borders of the unexplored, and to bring system and logic into dimly realized relationships. The "modular" construction, so universally agreed upon by the contributors to this volume, never would have developed to its present state without the enthusiastic promotion and painstaking application to all structural, mechanical and equipment components, which came from architects all over the country.

The distinguishing characteristic of the contemporary laboratory architect (or rather architect-engineer, since most architects of laboratory projects will have either engineering departments integrated with their staffs or long-range working agreements with engineering firms) is the practice of imaginative coordination. In other words, he must have the ability to see simultaneously all aspects of a program in their true interrelationships, and the knack of immediately visualizing the stated requirements in terms of three-dimensional space, construction materials, equipment, cost and appearance. Not that people in other occupations may not have the same natural endowment; merely that in the architect it is sharpened up as a tool used every day.

The ability of the architect to supply service of great value depends, therefore, to a large extent on the opportunity granted by the client. He will be most useful as a party to the planning of a new building from its very inception—while plans are still in the plastic stage of loose conversation, and certainly before the property has been selected. It is at that stage that many basic decisions are made and opportunities are either creatively exploited or definitely missed.

A successfully used method of procedure consists of the appointment of a building committee of which the architect is part, or at any rate to which he reports and in whose deliberations he participates. The building committee should preferably be headed by a representative of top management to insure proper interpretation of basic policies and budgetary possibilities. If these aspects are constantly before the committee members, the resultant recommendations are likely to have smoother sailing toward approval by the governing body.

Next and most important is representation of the users or using departments. In the case of laboratory buildings, the ultimate occupants may be research scientists, who do not always express themselves easily in terms of space or construction, are not necessarily at home in the more businesslike aspects of a building project, and who may quite properly be prone to single-minded preoccupation with their own particular phases of the work to be housed. It is often desirable, therefore, to have on the building committee someone with sympathetic understanding of the scientists', project leaders', or professors' problems. This person, perhaps the director of the laboratory, should have a Solomonic ability to adjust competitive demands within the framework of the budget, suggest possible common or multi-purpose uses of facilities, evaluate proposals for especially elaborate equipment, or provisions for future or contingent use.

The department in charge of maintenance should also be represented to pass judgement upon construction and equipment details in the light of its experience. That department will usually be in a position to supply information on utilities, heating or other centrally supplied services, availability of general shop facilities and labor, and organization of special shops that may be proposed for a new building.

Other departments should be consulted as the need arises. Arrangements of possible significance to labor relations or training should be reviewed with the personnel department. Maintenance of security and secrecy as well as fire fighting and protection of property may come under a plant-protection unit. The public relations director should be consulted about reception facilities, and the display of interesting products or processes, or other features that may have a bearing on conducted plant tours or other movements permitted to visitors. Also, his comments should be obtained regarding exterior appearance of the building. Where the laboratory library will function as a department of the central library, the person in charge of the latter should be consulted. Receiving facilities, stock rooms and issue counters should be reviewed with purchasing and storekeeping departments.

The architect should work closely with the building committee from the very start. The word "architect" is used here in the liberal sense, implying that he will be able to supply expert opinion and inventiveness on site planning, landscaping, structural and mechanical engineering, and budgets, either based on his own training and experience or by virtue of advice available to him from his own staff. In the more narrowly defined field of architecture, he will interpret building code requirements, suggest construction and service supply methods, materials, finishes, and timing and scheduling of construction. Above all, he will continuously and sometimes subconsciously synthesize the requirements, as they are being discussed, into a three-dimensional mental image, perceiving relationships, ironing out conflicts, and finding opportunities to consolidate and dovetail project elements that probably would not occur to committee members untrained in this particular discipline.

It is evident that a large amount of assembly and coordination of fact and opinion is needed in the work of the building committee. This takes time and patience. Architects are well trained for that task, and usually ready to undertake it. Sometimes the owner prefers to delegate that function to a person on his own staff; in that case, it is advisable to team up the architect with the coordinator, even though he is only a silent partner. This will give the architect a first-hand "feel" of the situation.

If this procedure is followed, and if the architect has the creative "touch", the statement of the requirements eventually evolved by the building committee will already imply the design solutions. Their translation into sketches and preliminary estimates, completing the report of the committee, will then be almost a formality.

The chapters that follow this introduction have been written by a number of experts with varying approaches and convictions. The editor has deliberately refrained from any effort to conciliate conflicting opinions or to eliminate the repetition caused by identical thoughts expressed by more than one contributor.

This restraint should make the book more valuable to the reader, because it enables him to weigh each statement according to the background and special field of the source authority, and because it creates a sort of a public-opinion poll of a highly informed group. Perhaps it would not be too far-fetched to add another observation.

Where opinions of equally qualified experts are at variance, further exploration, experiment and advancement may be taken for granted. But where general concurrence prevails, a warning signal should be run up. Perfect harmony is rarely reached in human affairs until the stage of creative development is completed and a certain amount of stagnation has set in; at which point, as likely as not, the art in question has begun to fall behind its time and a radically new departure may be in the offing.

It may be a facetious and unworthy thought—but will the standardized modules and service systems of contemporary laboratories, for example, be as obsolete in twenty years as the standardized columns and pediments of twenty years ago are today?

2

INTERIOR CONSTRUCTION MATERIALS

Edward M. Jenkins Johns-Manville Research Center, Manville, N. J.

The selection of construction materials for the floors, walls, and ceilings of a present-day laboratory is influenced by a greater number of factors than ever before. There are now many more kinds of laboratories, and as a result the demands upon laboratory planning and upon laboratory construction materials have become more diversified and exacting. The selection of materials for the interior construction of any laboratory is affected by a series of primary considerations as well as by a long list of less and less important requirements. The order of importance of any one consideration will vary in each laboratory. Beside such commonly recognized conditions as the method of distributing services within a laboratory—the lighting arrangements, heating, furniture, and so forth—there are less tangible but no less important requirements.

Dust—its type and amount—together with the necessity for cleanliness can materially affect the selection of interior materials. Dusts vary considerably in respect to their ease of removal. Some dusts, such as resins, plastics, bitumens, and others, may be adhesive and difficult to remove. Carbon black and some forms of pigments are also tenacious, while other dusts, such as wood particles and light inorganic dusts, present no special cleaning problem.

Corrosion caused by chemicals and gases of various sorts may attack any building surface, particularly when contact is maintained for a protracted period. A laboratory operation that promotes the development of air-borne particles or globules, or one that gives off fumes and vapors of a corrosive nature, will create a corrosive condition on the surrounding building surfaces, especially if ventilation is imperfect.

Noise, within or without the laboratory, may require careful planning of the building structure as well as of interior materials. Equipment or operations within the laboratory can develop an objectionable noise level, or the work being carried on may demand an unusual degree of quiet.

Vibration ordinarily is dealt with at the time the building structure is designed, it being recognized that equipment or other possible sources of vibration within the building, as well as exterior conditions, can produce objectionable vibration in the laboratory.

Moisture present in unusual amounts in the air can have a very bad effect upon surrounding structural materials, particularly if corrosive agents are present. Careful planning is necessary if excessive humidities or condensation on room surfaces are anticipated.

Unusual conditions occur so often in laboratory design that they may better be termed individual conditions. Conditions common to all laboratories may be called standard conditions. Individual laboratory conditions are infinitely variable, and cannot possibly be covered here. However, to serve with effectiveness, interior structural materials must be selected in the light of all known conditions, both standard and individual.

The kind of work to be done in the laboratory is the primary influence affecting the determination of interior surfaces and construction methods. At one time the processes within a laboratory were more or less well established, even in detail, so that the space devoted to housing the operations could be safely designed in an immovable and fixed form. The men working in the laboratory changed, but the laboratory did not. Space

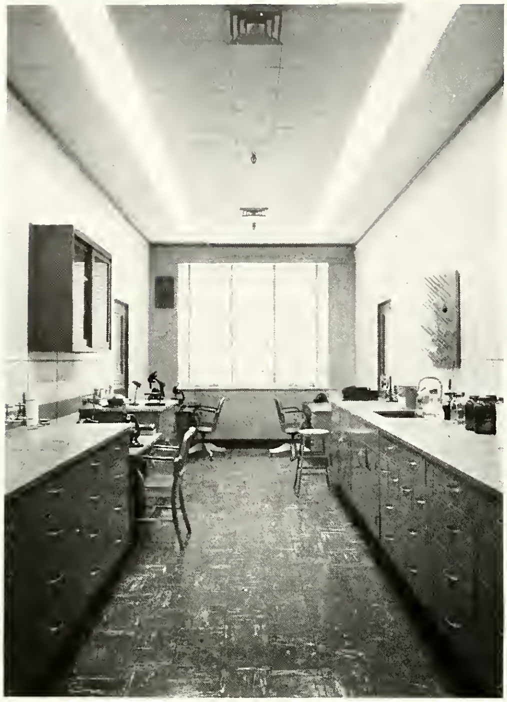


Figure I.1 Removable walls and ceilings are used in this laboratory.

arrangements and facilities were constant and relatively unvarying. There are still many laboratory classifications where fixed space and service are entirely satisfactory. Many laboratories for colleges and universities, small business laboratories, and those for institutional and business chemical work fall into this category.

In recent years there has gradually appeared a necessity for a new kind of laboratory where a variation in space utilization can be provided. This grew from a realization that in certain kinds of laboratory work it is impossible to forecast space and service demands. To meet the new conditions, laboratory structures were devised which permitted demounting and relocation of interior partitions. Figure I.1 shows a single laboratory unit with horizontal dimensions of 10'6" by 26'0" and with a hung ceiling 10'6" from the floor. The services, walls, and ceilings are movable.

The proportion of laboratory space provided with movable partitions can be made to vary from a single room to a fairly large proportion of the entire available space. The change from fixed to flexible space division has naturally had a profound effect upon the materials and construction of certain laboratory walls, floors and ceilings. On the other hand, the fixed space laboratory is, to a degree, a problem in planning rather than in construction. With known and set work requirements, the laboratory space can ordinarily be built to fit the specified work, so conventional structures and properly selected materials will serve satisfactorily. The flexible space laboratory is sometimes built from conventional laboratory materials, but usually the structure takes a different form. The movable laboratory partition, combined with movable furniture and services, can provide great flexibility of space usage. The concept of a room with immovable enclosing walls may be modified to the newer idea of an open area which may be subdivided and re-subdivided as desired.

Another new factor affecting the materials of and methods for laboratory construction is the recognition by business management of the value to be obtained from improved laboratory appearance and convenience. Pleasant and well planned surroundings provide a comfortable and attractive place in which to work. This attracts superior technical personnel, who, in turn, find greater satisfaction in their work, as well as pleasure in their surroundings. A second value that management gains through improved laboratory design is that the building itself may be used in sales promotion as proof of the progressiveness of the business to which it is attached.

The new demand for laboratory finish is reflected in interiors where surfaces are smooth and flush without molding or other projections, 1. color schemes are studied, 2. services, such as pipe work, ducts, and conduits are concealed, 3. lighting is carefully planned for effect as well as for proper illumination and, 4. air is conditioned. The attention directed toward the interior finish and appointments of a laboratory will vary with the interest of the owners in the use of the building for other than research purposes. In some new laboratories, appearance and convenience are a feature, while in others these factors have hardly been considered. There are values in the influence of surroundings upon technical personnel, and an element of publicity in all laboratories today, whether so planned or completely ignored. In any case, in choosing interior construction materials and finish for all kinds of laboratories the element of showmanship cannot be ignored, however far removed some types of laboratories may be from such requirements.

To the already multiple considerations influencing the selection of materials for the floors, walls and ceilings of a laboratory, additional factors must now be added. To the availability, cost, maintenance, length of life, corrosion resistance, strength, hardness, and ease of cleaning of a material, must be added the value of a finer appearance, of acoustics, and of movable walls with the related service distribution problems.

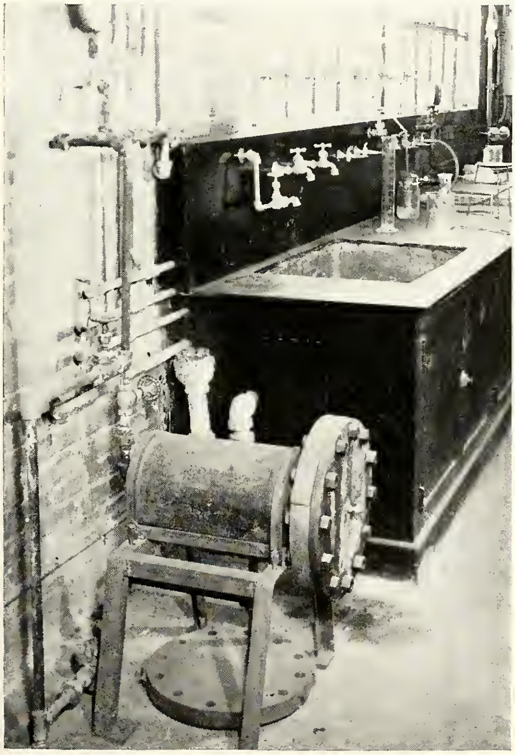
RELATION OF FLOORS, WALLS AND CEILINGS TO SERVICES

Three common types of horizontal service distribution within a laboratory space affect the construction and materials used in the walls, floors and ceilings:

a. Services on or in the walls.
b. Services in the furniture.
c. Services through floors or on ceilings.

When services are distributed on or in a wall, the wall may or may not be movable; if the wall is movable, the service lines themselves must also be easy to disconnect. A permanent, conventional wall will ordinarily have service piping supported on built-in pipe carriers or in metal race-ways. To conceal horizontal service pipe and improve the appearance of the laboratory, the usual method is to fasten the piping to the surface of the wall behind the bench runs. If such a distribution method is used, the walls are unaffected structurally, except that they must support the pipe carriers. Thus they may be built of any conventional wall material suitable for the conditions. When horizontal service pipe distribution hung on the wall behind benches is used, interruption of the bench run exposes the piping or pipe chase, and conversion of space to uses where benches and services are unnecessary is more difficult. The service piping exposed by the omission of a bench is shown in figure I.2. Service piping through or between bench runs, such as is common where a bench island is used, is supported on special racks resting upon the floor, or is fastened to the furniture itself. When flexibility of furniture arrangement is essential, the service piping should be easy to disconnect no matter how it is supported.

Figure I.2 Exposed piping is evident when table is omitted.



Horizontal distribution of service lines through the floor or on the ceiling requires construction materials and methods designed to accommodate the service distribution method. The hung ceiling, as described in detail below, is a favored method for concealing overhead distribution of pipes, ducts, and other services. When sufficient clearance for access is provided between the ceiling and its supporting structure or when other provision is made for convenient access, the hung ceiling is satisfactory. In a recent survey of more than twenty of the newer research laboratories, the hung ceiling was found to be nearly always used, either in the corridors, offices, libraries, toilets, the laboratories themselves, or in combinations of these locations. The corridors, with their unsightly and hard-to-clean maze of piping, conduit and duct work, were, as a rule, built with hung ceilings. The offices and similar spaces had the next greatest frequency of hung ceilings, and the laboratories the least.

The in-floor horizontal distribution of service lines is coming into favor since the introduction of floor systems that provide convenient hollow ways within the floor structure for pipe and conduit. Services, except large duct lines, can be made invisible in this manner. One advantage of in-floor service distribution lies in the possibility of using island benches where passage is provided around both ends of the island without having to resort to exposed piping. The same island circulation system without visible pipe runs can be had with overhead services concealed behind a hung ceiling below the floor to be serviced.

FLOORS—CONSTRUCTION AND MATERIALS

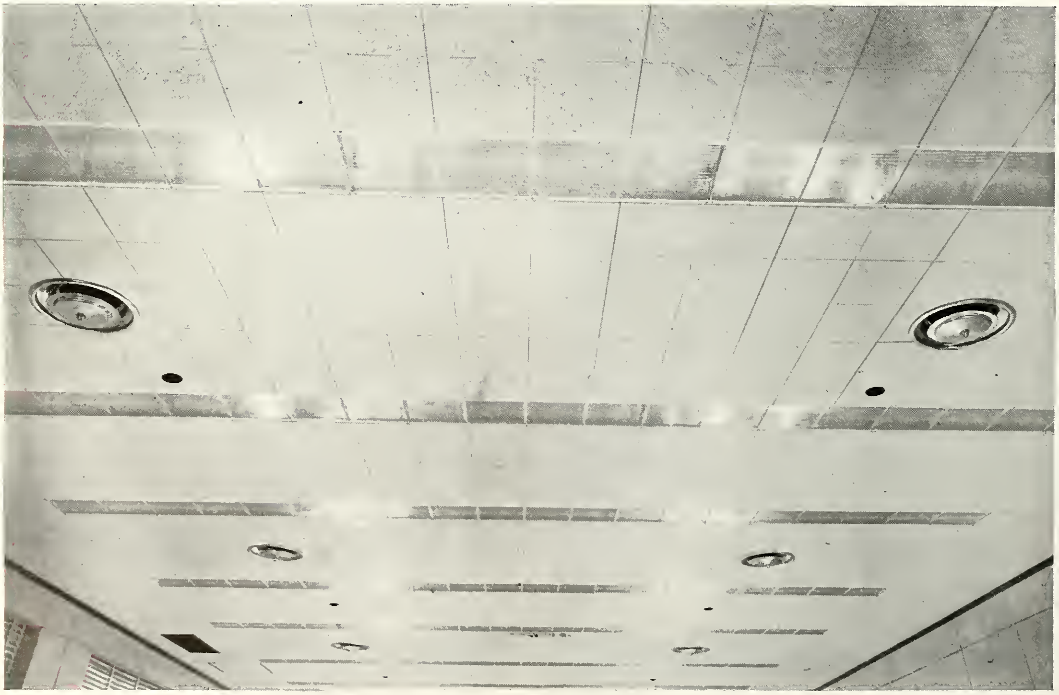
The structural materials of a laboratory floor are as varied as in any similar number of industrial buildings, with the same variation in quality, fire resistance, and size. The materials used for the laboratory floor will depend upon a variety of controlling factors, just as in an industrial building. The use to which the building is to be put and availability of materials and funds are some of the controlling factors. Since laboratory buildings are usually substantial structures, the commonest structural floors are the concrete slab or the flat masonry arch.

Services within the laboratory are usually distributed either below the floor or across the ceiling. Thus services are available at the point desired by bringing the piping up through the floor or dropping it down from the ceiling. Such a distribution method is convenient for installation and repair but is unsightly and difficult to keep clean. Accordingly, various methods have been devised to eliminate exposed piping, conduit and ducts. The method most used is the hung ceiling, but the in-floor method has more recently come into favor for at least a part of the service lines. One of the older floor distribution methods consists of pipe and conduit laid across the surface of the rough slab covered to floor finish level with cement-cinder fill. This method has not been used extensively because of the original cost as well as the difficulty in alteration and repair. A more recent in-floor distribution system consists of bent steel members which provide convenient ways through the floor structure. In some cases, the bent steel members are a structural part of the floor.

The materials and structural part of the laboratory floor need meet only the standards required in any similar building, but the floor coverings of the laboratory must receive special attention because often they must offer resistance to acids, alkalies, oil, grease, and other substances often used therein. At the same time, the floor finish should provide a comfortable surface to stand and walk upon, a pleasing appearance, long life, and ease of maintenance. A recent extensive survey showed seven materials in common use for laboratory floor surfaces. In order of frequency of occurrence these were asphalt tile, painted concrete, linoleum, asphalt mastic, quarry tile, terrazzo, and wood. Floors in offices, halls, libraries, toilets, and other non-laboratory spaces were sometimes covered with other materials depending upon the conditions of service. Asphalt tile, quarry tile, and terrazzo were used most often in corridors and hallways for appearance, long wear, and easy maintenance; but in the library, where quiet is essential, softer surfacings such as rubber tile and cork were installed. No unsurfaced concrete was found in the corridors or offices, but it was common in the laboratories.

As mentioned above, special service conditions in a laboratory may dictate the floor surface. A floor surfacing that must be sparkproof and grounded, as well as acid-, alkali-, oil-, or solvent-resistant will necessitate special selection. Floor surfacings such as asphalt tile, linoleum or exposed concrete have been generally satisfactory, as is indicated by present extensive laboratory application. Very hard floor surfacings such as terrazzo, quarry tile and concrete are often overlayed before benches and at other points with rubber or linoleum mats for the comfort of the laboratory worker. Recently, several types of "plastic" tile, similar in appearance to asphalt tile, have been introduced. These new tile are promising for laboratory floor surfacing because some have a high degree of resistance to acids and alkalies, while others are designed to be oil-, grease-, and solvent-resistant. In addition, some of the new tile are more resilient than asphalt tile and are easier to stand and walk upon.

Figure 1.3 Note the neat appearance of this laboratory with a hung ceiling of removable units, and the handling of lighting fixtures, fire alarms, air conditioning inlets and outlets, and hood ducts.



CEILINGS—CONSTRUCTION AND MATERIALS

Laboratory ceilings receive lighter service and are required to do less than the floors and walls. A ceiling is subjected only to comparatively mild forms of damage, and the materials of which it is constructed or finished need not have the weight or strength necessary in floors and walls. In many laboratories the corrosive conditions at the ceiling are very mild or non-existent; the tendency, in fact, has been to overbuild all parts of a laboratory in the matter of corrosion resistance. Beyond enclosing and isolating the space and improving appearance, a laboratory ceiling must support lighting fixtures, heating, air-conditioning and hood ducts, service piping, and, in addition, it must reflect light. The ceilings of present laboratory buildings are usually merely the exposed side of the floor or roof structure above. Their attractiveness depends upon the flatness and neatness of the underside of the over-head structure. The underside of a concrete slab so frequently used in laboratory construction is sometimes smoothed by stoning or by an application of plaster. In other cases its smoothness depends upon the form work that was employed; occasionally this produces a comparatively rough ceiling. Paint, preferably chemically resistant, is applied to the slab ceiling to improve light reflectance and appearance.

The appearance of a ceiling formed by the under side of the over-head construction is usually spoiled by exposed service piping, conduit and ducts running across it to service the laboratory space above or the laboratory in which the piping is exposed. The hung ceiling has been used for some time to conceal overhead service lines and structural members in offices, libraries, corridors and other non-laboratory areas. In the past the hung ceiling has been omitted in laboratory areas for three reasons: 1. the necessity for frequent access to the numerous service lines for additions, replacements, or repair, 2. lack of interest in the appearance of the laboratory areas, 3. added cost of the hung ceiling. Hung ceilings composed of removable units are now in use in laboratories; these are an answer to the first reason for omitting ceilings. A laboratory with a hung ceiling made with removable units is shown in figure I.3. The second and third reasons advanced for continuing the use of exposed ceilings in laboratory areas are gradually being overcome by the desire to have the laboratories themselves as pleasing in appearance as the non-laboratory areas.

At one time the hung ceiling was constructed of metal bars covered by metal lath and plaster. Now such a ceiling may also be built of metal bars and factory finished, friction fitting metal or other units, or, of wood runners and panel units held in place by screws.

The metal units or panels are often factory-finished and need little maintenance for a long period. In areas where unusually high corrosive conditions exist, parts of a metal fabricated ceiling may be made of stainless steel or some other corrosion-resistant material. When a hung ceiling is used in a laboratory the construction may include a sound-absorbing material, thus providing acoustical treatment at little additional cost. Such a ceiling is particularly desirable when glazed surfaced walls, terrazzo or concrete floors and other hard, sound-reflective surfaces are present in the room. If cleanliness or corrosion resistance dictates the use of smooth, hard surfaced walls and floors, the laboratory will be a more pleasant working space with proper acoustical treatment.

WALLS—CONSTRUCTION AND MATERIALS

Laboratory walls can be divided into two categories —structural and non-structural. Structural walls are a fixed part of the building—principally outside walls but sometimes interior load-bearing walls as well. The non-structural wall is a space-dividing partition carrying no building loads. It normally comprises a greater wall footage in any one building than the structural wall. The laboratory non-structural wall or partition may be subdivided into three classifications: the fixed and immovable partition, the semi-movable partition, and the movable partition which is completely demountable. Every laboratory building has a certain number of structural walls which are established by the outline of the building, are fixed and immovable and enclose the available space. The dividable space will be subdivided by walls which will vary in movability from all immovable through partially movable to practically all movable. Recently when semi-movable or demountable walls were used they have been combined with fixed walls. Corridor, toilet, auditorium, library, and similar walls are likely to be fixed while cross-walls and similar laboratory walls are more or less relocatable. Without doubt movable wall systems have provided a greater latitude for future laboratory planning.

The structural wall generally receives the same surfacing as the balance of the laboratory walls regardless of the type or finish of the adjacent partition wall. In a recent survey material used for the fixed laboratory partition was found to be divided between masonry units plastered or painted and special masonry units with a glazed surface. Cinder and concrete block, terra-cotta tile, cement and clay brick and gypsum block were the types of masonry units found. Clay brick, terra-cotta tile, and, occasionally, unglazed masonry block over laid with thin glazed tile were the types of glazed masonry units found. Glass block, erected with and without mortar, were also used. In laboratories where walls required washing or where walls must be unusually corrosion resistant, glazed surfaces were most in evidence. There were locations, however, where glazed surfaces were applied and unusual conditions did not exist. Plastered walls were painted with ordinary or chemically resistant paints depending upon the service requirements.

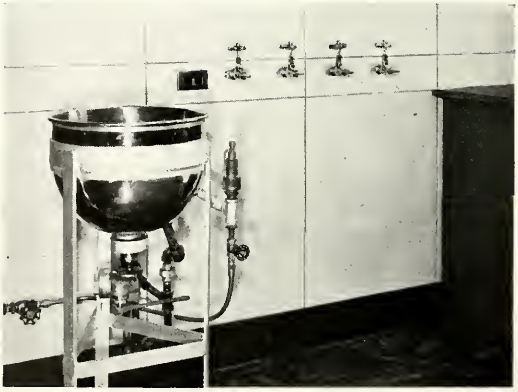
Walls of masonry are a definitely immovable structure and are of the heavier wall types. While weight does not often present a problem in one- or two-story buildings, it may be an appreciable factor in taller laboratory structures. On the other hand, the weight of a masonry wall has an advantage in resistance to sound transmission, the heavy wall sound-isolating the space it surrounds more effectively than would a lighter wall structure without special design and construction. The masonry wall also has a high resistance to fire passage, a characteristic of value in certain types of laboratory work. If the masonry wall has a hard or hard and glassy surface, it will also have a high sound reflection that may be sufficient to produce objectionable acoustics.

In laboratory work, it is often convenient to attach apparatus or other equipment to the walls, yet this is difficult to do if the wall is of masonry construction. Metal clips fitting standard bolts, metal channels and wooden grounds placed in the masonry during construction are commonly used to provide means for attaching equipment and apparatus to laboratory walls of masonry construction. Wood grounds embedded in the masonry are imperfect because the placement of grounds complicates construction, the grounds may loosen and deteriorate with time, and, unless placed on close centers, they are often not in the positions where they are most needed. Slotted metal grounds and clips are stronger and more reliable than wood, but also complicate construction and are subject to placement errors.

Walls classed as semi-movable are those for which no special design allowance has been made for removal or replacement, but which at the same time are at least partly salvagable. Glass block assembled without mortar and wooden stud walls with screw-attached panels are examples of semi-movable walls. A varying percentage of material of the wall may be salvaged and re-used when a semi-movable partition is removed. In addition, the semi-movable wall sometimes has these advantages: low first cost, light weight, and a degree of movability. The service such a wall can satisfactorily withstand depends upon the materials of which it is made, the construction methods and the conditions to which it is exposed. Semi-movable walls may either be made in the form of panels fastened to wood or steel frames, or they may be of lath and plaster applied over wood or metal frames. Panels are made of several different materials: hardboard; plywood with a plain or special surface of paint, plastic, or metal; asbestos-cement; metal or wood-surfaced panels with cores of treated paper or other material. The weight of a semi-movable wall varies but it is usually lighter in weight than a masonry wall. Some semi-movable walls have good fire resistance, others do not. This depends largely upon the materials of which they are made. Some semi-movable walls are superior to masonry walls when the matter of fastening apparatus or equipment to the face is considered, others offer little or no improvement; this depends on the construction of the wall. Some semi-movable walls are easy to maintain, while others require considerable attention. Generally speaking, maintenance problems are about the same for semi-movable walls as they are for similarly surfaced masonry walls.

The completely movable wall is a rather recent development in laboratory construction. It is used to give spatial flexibility that had been unattainable previously, because the removal or relocation of other types of walls is accompanied by construction difficulties and added costs. It is necessary to consider the type of service piping distribution no matter what type of laboratory wall is used, but this is especially true with the movable wall since moving a wall may also involve moving service piping. Unlike the structural or semi-movable wall, the service piping in a completely movable wall must be readily demountable if it is supported by the wall. The piping in one of the movable laboratory partitions that has been developed is enclosed within the wall as shown in figure I.4. Movable wall systems are composed of parts or units which fit together and have some reversible method for fastening parts in place. At present all movable walls are made of metal or asbestos-cement. The metal systems are most often made of sheet steel and are of two types: one a flush or flat unit; the other, a panel unit. The flush unit has a mineral-fiber filler to reduce drumming noise, the transmission of sound, and to improve fire resistance. The panel type of unit may have a wood fiber, corrugated kraft paper or similar filler for the same purposes. The finish of the metal panels may be any established metal surfacing, but it is as a rule baked-enamel, similar to the finish used for metal laboratory furniture. Because the surface sheets are thick enough to prevent drumming, and their weights are sufficient to prevent undue sound transmission, asbestos cement wall systems do not require a filler. Where extra fire resistance or further reduction in sound transmission is required, asbestos cement walls are filled

Figure I.4 This removable partition conceals service piping in the wall.



with mineral wool. The asbestos-cement surface is painted, enameled, clad in metal or wood, or a colorless coating may be applied, thus maintaining the color of the asbestos-cement sheet itself which is made in a variety of colors.

The use of movable partitions in all parts of a laboratory is unusual and seldom necessary. Certain types of movable walls are designed especially so that excellent provision is made for hanging apparatus, wall furniture or other equipment upon them; other types make no such special provision. Movable walls are usually satisfactory in corrosion resistance and maintenance, but, as with semi-movable walls, variations in service value are present because of the variety of materials and finishes available. When movable walls are used, large floor and ceiling areas are sometimes completed, including even the final finish, before dividing partitions are erected. Thus, a large area subdivided by movable partitions can be rearranged with a minimum of disturbance.

WINDOWS

Windows in outside walls are primarily for light and ventilation. The window also fills a psychological need, however, as indicated by the present lack of enthusiasm for windowless laboratories, even though windowless buildings are practical to build and operate. The laboratory window has other uses too; it may be used in an emergency to admit fresh air, or it may serve as an escapeway. Outside windows are a part of the exterior design of a building, and, therefore, are influenced by the architectural elevations. They must also be planned in relation to the interior partitions running to the outside walls. Individual windows were used most often in monumental and institutional laboratory buildings of the past. Lately there has been a trend toward the use of large, multi-section, industrial type windows. The larger glass areas provided by newer laboratory windows have many of the advantages, as well as some of the disadvantages, of older types of industrial windows. Heat losses are higher, glare lighting must be avoided, condensation may be a problem, cold drafts are likely to occur in cold weather and there may be objectionable heat radiation from the glass surfaces in summer. On the other hand, properly modified and diffused, the large glass areas provide excellent daylight illumination at considerable depths into the room with a minimum of objectionable shadowing. The problem of drafts in cold weather may be met by a properly designed heating system and good tight windows. Even so, it is seldom entirely satisfactory to place a desk near a large glass area.

In a survey made of the newer laboratory buildings, it was found that steel window frames and multi-section steel sash were used most frequently. A few laboratories were equipped with double-hung steel sash and in one or two cases the old style pivot-section steel sash were used. Wood frames and sash were employed in fewer than one-quarter of the laboratories inspected, and in nearly every case these were double-hung. No metal-clad wood frames or sash were found. With two exceptions, both frames and sash, whether the latter were multi-section or double-hung, were of untreated steel. In one laboratory, however, lead-coated steel windows were found; and in another, solid aluminum.

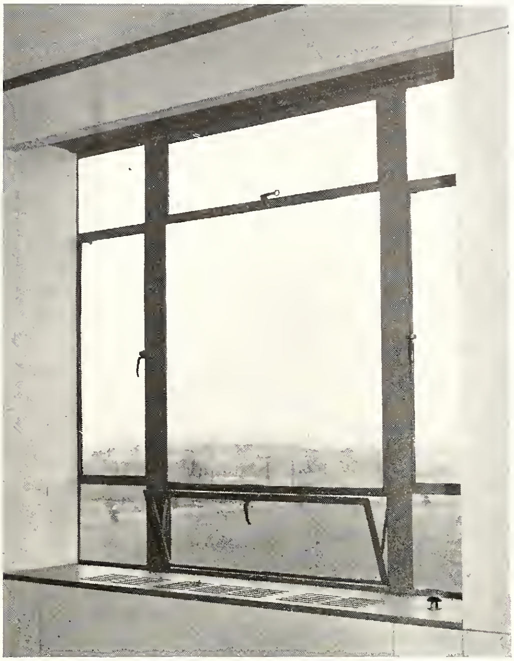


Figure I.5 Multi-section steel frame and sash has lower panel ventilation.

Multi-section steel frames and sash are made in a variety of styles, types and sizes, one of which is shown in figure I.5. That steel windows have served their purpose well in laboratory service is demonstrated by their selection for past and present construction. Quality in steel windows depends on manufacturing perfection and design. A poorly made or faulty steel sash leaks cold air and rain as badly as any other poor quality sash. Plain steel rusts and thus may require frequent maintenance. Though coated, rustproof steel or some other non-corrosive metal windows cost more, they may be economic and advisable under certain laboratory conditions.

The window should not only admit daylight but should admit it in proper quantity, properly diffused. The use of colored or obscure glass over most of a large glass area is advisable. This will reduce excessive brightness, and, properly designed, will help distribute the light. Panels at normal eye level are usually glazed with clear glass, making it possible to see outdoors. Multiple layer window panes have been devised to reduce heat flow through glass surfaces. Special obscured window glass is also available; this material helps maintain comfort conditions during hot summer days. Since these special types of glass are, of course, more expensive than ordinary glass, their value must be weighed for each installation.

If the laboratory is provided with year-round air conditioning, windows are usually kept closed so their function as ventilators is unimportant. When the window must be used for ventilation, however, frame and sash must be selected for their ability to provide fresh air without objectionable drafts and without admitting rain. If the opening is to be screened against insects, windows that are easily opened while screened should be chosen. The window shown in figure I.5 is one available type that is designed to reduce drafts. Double-hung windows also may be equipped with draft guards. Many types and styles of metal windows will serve to exclude rain sufficiently when partly open. Insect screens are a problem but are essential in some laboratories located in the United States. Completely inward opening or double-hung sash simplifies the screening problem because screens may be installed outside. Outward opening sash must have screens that are easily removed, or they must be equipped with some kind of a controlling mechanism so that the sash may be opened and closed easily with the screen in place. Only a small portion of the window area is movable on the larger metal windows, so that screening can be confined to the small movable sections.

Besides outside windows there are other window-type openings in interior walls and partitions. Partially glazed interior walls are familiar in office partitioning but they are not so often used for laboratories. However, desk or office space is occasionally closed off from a larger laboratory area and uses borrowed light that is admitted through a partially glazed interior partition. Such glazing is fixed. Ventilation is obtained through windows in outside walls by mechanical means or by the use of transom openings. Clear glass is used frequently for interior partitions to provide a means for inspection of activities in one room from another. Interior partition glass areas can be built into any type of partition, the only precautions being that wall loads or distortion do not cause cracking of the glass, and that the glass must be firmly seated to prevent rattling. There are types of movable partitions especially designed to use where borrowed light is required.

DOORS AND TRIM

It is generally less troublesome to select a laboratory door that is built of the right materials than it is to determine the type of door needed, its width, proper location, swing, hardware, and other details not directly connected with door construction. The laboratory door, at one time, was always made from wood; usually it was a panel door. Flush-panel wood doors were used occasionally but did not become popular until the present reliable doors of this type were produced. Wood doors were usually painted, although transparent finishes were sometimes applied. Wood doors have a satisfactory record for ordinary laboratory uses and recently panel and flush-panel styles have been used in increasing numbers in laboratories. A new type of flush-panel wood door is now available with a light-weight core instead of the solid wooden core used in older flush-panel door construction. Because certain laboratory doors may be quite wide, the weight of a door is sometimes important. It is not unusual in an occasional laboratory to find standard hinged doors up to three and one-half or even four feet wide. Wood panel doors, wood flush-panel doors with light-weight cores, metal flush-panel or panel doors of aluminum or other light-weight material, are the lightest doors available. The flush-panel door has often been selected for installation in laboratories because its smooth, flat surface is easier to clean, and because there is no place for dust to collect. The flush-panel door also harmonizes with the flat, flush, interior surfaces that are so much in use these days.

Glazed doors are used between a laboratory and a corridor or some other area where borrowed light is of value. If clear glass is used, the room may be inspected from the outside without having to enter. Privacy between rooms may be maintained by using obscure glass in doors; at the same time, this permits the transmission of some light from room to room. Transoms and side lights are sometimes used to augment light and ventilation at the door opening, whether a solid or a glazed door is used, but this method is not encountered in laboratory design as frequently as it used to be.

The materials from which doors have been made up to the present time have served satisfactorily for general laboratory application. If metal or wooden laboratory furniture that is satisfactorily corrosion-resistant is used, it is probable that metal and wood doors similarly treated would also be satisfactory. Special problems will arise, and, for these, a special door selection must, of course, be made. A degree of fire resistance is one such problem, and has been met with special wood and metal or metal-clad doors made for the purpose. Unusually corrosive conditions can be met by using a protective coating or by using doors made of corrosion-resistant material. Excessive humidity creates a difficult problem and the selection of a door for that condition should be carefully made. Doors resistant to the passage of air-borne sound are obtainable. These are heavy in weight and are provided with gaskets designed to sound-proof the entire perimeter of the door. Escape doors are similarly constructed and given the same finishes as standard doors. Escape doors are referred to elsewhere in this book.

Less trim is required in more recently designed buildings than was customary in the older designs. This makes the building easier to keep clean and reduces the first cost. Trim around doors and windows is now seldom used. Instead, wall sheets, panels, or plaster is run up flush to the door or window frame. Where trim is still used, it is often flatter and narrower than in older buildings. Baseboards are still used extensively, and sometimes moldings are used at the wall-ceiling junction. At one time, all trim was made of wood. Now sheet and solid metal as well as composition materials are used. Metal and wood moldings require the same protective coatings that are necessary elsewhere in the laboratory.

The base molding, providing a closure between wall and floor surfacing or furniture and floor surfacing, is most important. This molding protects the walls and furniture from damage caused by cleaning equipment and from other sources. The base molding should be close fitting, neat in appearance and dark in color to prevent soiling caused by floor wax or other materials that might come in contact with it. The base is sometimes coved to help keep the floor-wall junction clean. Some flooring can be turned up along the wall as far as desired. Special molded cove bases made from similar materials are available for asphalt and plastic tile floors. Cove bases are available for ceramic tile floors with finishes to match or to contrast with floor or wall tile.

Movable walls and furniture are usually provided with easily removable base molding and other trim. When the plan is to use movable furniture it is often possible to continue base and ceiling moldings behind the furniture so that when the latter is removed it is not necessary to change the moldings.

BUILDER'S HARDWARE

Hardware is one of the most important items in a laboratory building, yet it is frequently slighted. Imperfect hardware that is frequently out of order can be more annoying and worse looking than any other part of the laboratory. Builder's hardware represents a small percentage of the laboratory cost regardless of its quality, and the best obtainable should always be specified. This hardware includes such items as door hinges, locks, knobs, escutcheon plates, door closers, kick plates, emergency door catches, window locks, adjusters and hinges, transom hinges, and catches and adjusters, all of which are found in a laboratory.

Good quality standard hardware articles are suitable for the laboratory provided no special conditions are expected. If such conditions are to be met, special selection of hardware is required. In the chemical laboratory, hydrogen sulfide attacks hardware to such an extent that a selection with that gas in mind is advisable. Bronze, brass, and most other metal surfaces will be attacked by hydrogen sulfide. However, aluminum, some aluminum alloys, and chrome plate stand up very well and special lacquered surfaces also are available. Plumbing and electrical hardware, discussed elsewhere in this book (see pages 37 and 58), will be subject to the same chemical attack as builder's hardware.

PAINTS

The selection of paint for a laboratory surface is governed by the material to which the paint is to be applied and the conditions to which the paint is to be exposed. In laboratories where only mildly corrosive conditions exist, paints will be chosen for conditions or properties other than their corrosion resistance. Under more severe corrosive conditions, paint selection should be made with extra care both as to pigment and vehicle. Various paints having excellent corrosion resistance are available. Among these are rubber base paints, vinyl and acrylic types, and enamels with an alkyd or urea alkyd base.

A water-base paint may be used on ceilings when conditions permit. It is easy to apply and low in first cost. Standard grades of oleoresinous paints will be suitable for ceilings as well as walls, if no corrosive problem exists. Concrete and plaster surfaces may be painted satisfactorily with rubber, vinyl-, or acrylic-base paints. Concrete floors can be satisfactorily painted, as far as paint adhesion is concerned, with any of the good concrete coatings, as noted above. Wood surfaces may be painted with the same type of paint as concrete although the paint may sometimes be of a different formula. Steel surfaces, such as furniture, doors, window frames and sash may be painted with air-dry paints or they may be obtained already treated with baked-enamel. Where a high gloss coating is required for ease in cleaning or for other reasons, the coating can be obtained in standard or special synthetic resin enamel. There are a number of types of gloss enamels, some having a vinyl, alkyd, or acrylic base. Normally, strong highlights are not desirable on painted surfaces. To avoid highlights, a semi-gloss or flat finish may be used.

Colors are usually chosen on the basis of what they will do to improve the appearance of a room, but it is important also to consider how the colors chosen will affect the reflection and diffusion of light. Paint may be used to increase or decrease light intensity in a laboratory. Colors, as they affect general appearance and illumination, should be carefully studied before the paint is selected.

It can be assumed that paints are available which will adhere satisfactorily to any ordinary laboratory surface. There are also paints available which will resist many of the troublesome corrosive conditions so often encountered in laboratories. Such paints are made by almost all the large paint manufacturers, who are in a position to assist in the selection of the proper paint for any particular service.

3

FURNITURE

By a Committee of Members of the Laboratory Equipment Section of the Scientific Apparatus Makers Association.

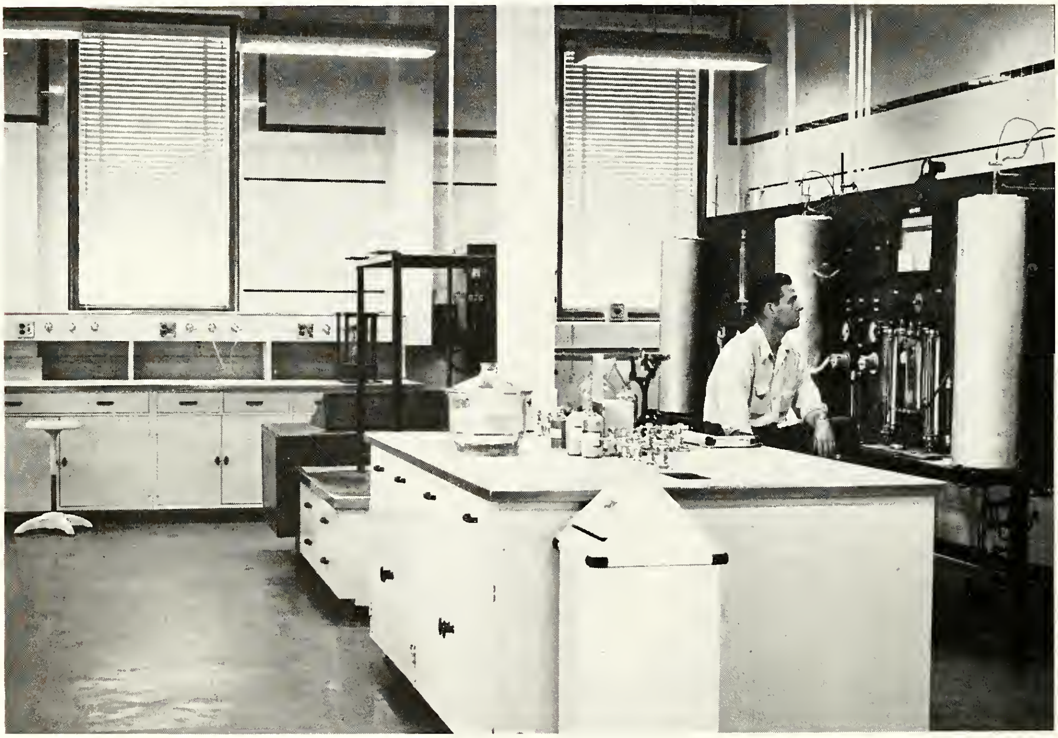


Figure I.6 This illustration makes plain the necessity of providing space for large pieces of apparatus. Such pieces require wall space.

This section deals with the design and construction of laboratory furniture, the arrangement thereof in the laboratory and the accessories that ordinarily are a part of the equipment. When a laboratory is being planned it is necessary to arrange the furniture to provide for the accommodation of standard apparatus such as analytical balances, ovens and hot plates, Kjeldahl units, titration setups and various pieces of special apparatus as required by the type of work to be done in the laboratory (see figure I.6). If items such as those mentioned are portable, they are usually obtained from laboratory supply houses rather than from laboratory furniture builders. If such units are built into the equipment, they then become a part of the furniture and are best supplied by the furniture manufacturer and installed with the laboratory furniture, thus avoiding divided responsibility.

Building construction materials and services are not a part of this section, but it appears wise to mention a few instances where their relationship to laboratory furniture is very close.

Extreme care should be taken to have laboratory floors and walls level, plumb and straight, so that expensive cutting and fitting in the installation of the furniture will be eliminated. If the finished flooring is a compressible material, firm foundations should be provided for large furniture units so that they will not settle after installation. Building services, such as ventilation, location of heating units and arrangement of service piping, are closely tied up with the design and arrangement of the laboratory furniture and it is most desirable that they are not too definitely fixed before their relationship to the finished laboratory is determined.

Laboratory tables are subject to many varieties of service. Also, a laboratory table is usually much more than just cabinetwork and a top, such as is found in other types of furniture like office desks and tables. There is a considerable choice of working-surface materials and a wide variety of cabinet designs is available. Besides, the selection of accessories and their incorporation, together with the essential service connections needed to make the table complete, is a real problem. These extras found in chemistry and other laboratory tables comprise such items as sinks, hoods, special tanks and baths, service fixtures, and waste lines and traps (see figures I.7 and I.8).

Consequently it seems advisable to consider the component parts of equipment individually. This will make reference easier since complete data on one subject will be found in one section. This method also aids in the planning and selection of materials and designs from the standpoint of the service required of the equipment.

The component parts of a laboratory unit or table can be classified under the following heads:

A. Table tops or working surfaces
B. Cabinetwork and other top supports
C. Sinks, drainboards and troughs
D. Hoods and other fume disposal units
E. Storage and display cases other than table cabinets
F. Accessory equipment such as baths, hot plates, etc.
G. Service fixtures and lines, waste lines and traps

TABLES

The term "table" is often used synonymously with bench and desk. In this discussion "table" is intended to refer to any article of furniture at which special laboratory work is done. "Bench" will refer to types of tables usually found in physical testing areas, machine shops, and assembly and inspection departments. "Desk" will refer to office or writing desks, reading tables, reference tables and the like. This classification may be broken down further by subject as chemistry, physics, and biology or by function such as general tables, instructor's tables, laboratory trucks, darkroom tables, microscope tables, and tables to support special apparatus, such as spectrographs and densitometers, balance tables and cases, titration tables, polishing tables, etching tables, set-up racks or condenser lattice-rack tables, and glass working units (see figure I.9).

Often there is a need for special tables, that is, tables designed and equipped to meet some particular or peculiar problem. The more nearly these special units can be kept standard the better it is, not only from the standpoint of cost but also from that of utility if, and when, the special requirements change. It sometimes happens that the very special features incorporated into a laboratory unit arise from the desires of personalities rather than from the physical requirements of the work at hand. Many times a unit can be found in laboratory equipment catalogs that can be made to meet requirements without too much specialization or change. It is usually better to modify an existing unit than to develop a completely new one. Construction and engineering problems often arise that become extremely difficult once a new design is put into production.

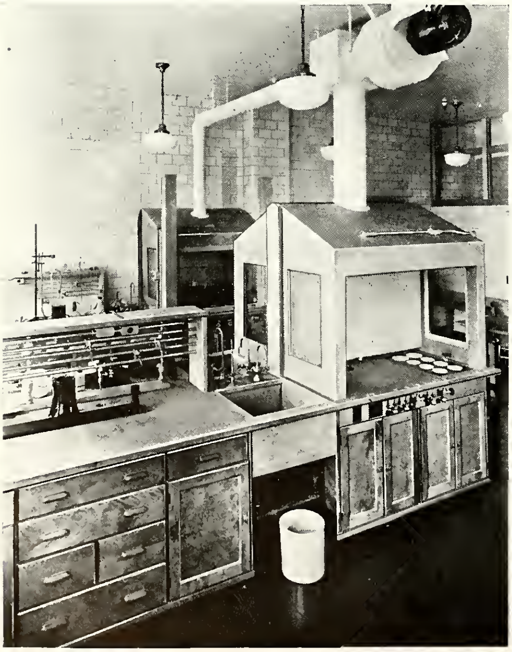
On the other hand, many of the standard designs found in the furniture catalogs were once special tables. Hence it is good practice to consult experienced laboratory equipment engineers whenever special problems arise. Then, in case an existing design cannot be modified to meet the requirements, a practical unit, at least, will usually be suggested—practical as to construction and production as well as to function.

The manufacturing of laboratory furniture is a specialized industry. The cabinetwork is only one part of the laboratory unit. It is questionable, when all things are considered, whether a satisfactory result is obtainable by breaking down the table into component parts and then ordering these parts from unrelated sources. This is particularly true of the practice of obtaining cabinetwork from ordinary commercial sources. While the first cost of millwork may make the price picture seem attractive, the whole matter of special design must be considered. Millwork is not adaptable to the specialized requirements of laboratory equipment, especially the requirements of teaching laboratories. Ordinary cupboard and drawer units of mill construction will suffice for simple testing purposes; but in the case of the more complicated laboratory equipment, once the cabinet is produced, the problems begin to accumulate. Specialized finishes, corrosion-resistant trimmings and hardware, accommodations for plumbing and other services, and assembly of cabinets into work units are only a few of the engineering details.

The firms within the laboratory furniture industry have well organized and trained engineering groups. Their engineers are thoroughly familiar with the special problems of laboratory coordination.

It may be well to comment here on the matter of the relative costs of standard or production items versus special designs or modifications. With modern production methods the relative cost of standard units has been materially lowered over a period of time. However, because of the nature of this production procedure, any modification from standards immediately increases the costs. Accurate cost records have proved, time and again, that this cost is not a small percentage of base cost. It runs into as much as two or three times the base cost. A production item priced at $50.00 can easily cost $150.00 if produced singly in a special department, even when production parts are used in the assembly. For this reason standard items should be specified if at all possible. If special lengths or widths of tables are required to fit wall or room spaces or to meet special operating requirements, it is possible, without great extra cost, to utilize standard cabinets and top supports with front and end filler plates to provide a finished appearance. Special sizes of tops, sinks, troughs, shelves, and hood superstructures usually may be had at little or no extra cost.

Figure 1.7 Cupboard units below fume hoods with services and controls mounted on the wide apron rail of the base cabinet. Note the steam bath mounted flush in the working surface of the hood. A sink adjacent to the hood may be used as a cooling tank. On the left is shown a method of mounting fixtures on horizontal lines below a reagent rack. The top line is electrical, keeping it well away from the water fixtures. This figure also shows a method of mounting the exhaust fans and for carrying ductwork.



Owing to the volume of equipment required by the laboratories of the nation, the industry has been enabled to supply specialized equipment in production units at costs comparable to the cost of ordinary, commercial-grade equipment.

Tabletops or *working surfaces* should be specified with their most common use in mind. For chemical work, a top as nearly as possible impervious to alkalies, acids, and solvents should be selected. It is not the purpose to recommend any specific material for definite applications. The best that can be done is to list the various types of working surfaces and suggest their possible applications. Final decision as to the materials to be named for specific application is a matter of judgment based on the chemical and physical characteristics of the various materials offered by the laboratory equipment industry and the relation of these to the intended use. It is important to remember, however, that the working surfaces of laboratory tables are subject to abuse, and careful consideration should be given to the selection of materials which will stand up through the years with a minimum of maintenance.

Wood tops for chemistry tables are usually made of selected birch or maple glued up in strips not more than 3 inches wide, with a final thickness of 1¼ to 1⅝ inches. These tops are ordinarily treated with potassium chlorate and alternate coatings of copper sulfate, hydrochloric acid, and aniline oil, and are either washed with soap or treated with potassium dichromate to obtain a jet black color. The following formula and instructions may be used for applying black acid-resisting finish to wood tabletops.

Prepare three solutions as follows:

Solution no. 1—1½ pounds copper sulfate crystals
1½ pounds potassium chlorate crystals
2 gallons hot water
Solution no. 2—3 quarts muriatic acid
1 quart aniline oil
2 gallons distilled water
¼ pint solution no. 1
Solution no. 3—12 ounces potassium dichromate dissolved in 1 gallon boiling water

All solutions should be stored in earthenware or glass jugs.

Instructions for applying:

1. Thoroughly clean top to be finished, being sure that any wax or oil is removed.
2. Solution no. 1 should be heated to the boiling point and applied with a stove brush, brushing solution well into the top. Let dry four hours.

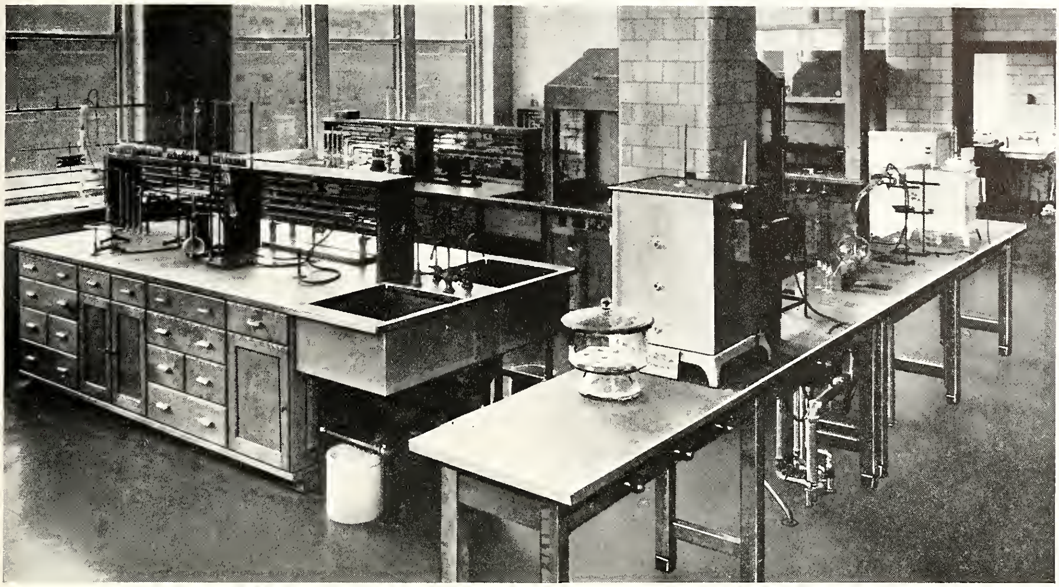


Figure I.8 Wash sinks or large disposal sinks at the end of a work-table. This figure also shows the use of open-frame tables where unusual widths, lengths, or heights may be required for special purposes.

3. Apply solution no. 2 cold, brushing in well with a stove brush and let dry for four hours.

4. Apply second coat of solution no. 1 at boiling point. Brush in well with stove brush and let dry overnight.

5. Apply second coat of solution no. 2 to top. Apply cold, brushing in well and let dry a minimum of four hours.

6. Apply first coat of solution no. 3. Apply cold, brushing in well with stove brush and let dry four hours.

7. Apply second coat of solution no. 3. Apply cold, brushing in well with stove brush and let dry at least overnight.

8. Apply a solution of a mixture consisting of half benzene and half raw linseed oil. After this coat of oil is applied, scrape the top surface and edges with a steel scraper to remove only the raised grain. Be very careful not to scrape through the finish.

9. After the raised grain has been removed from the tabletop by scraping, rub in the direction of the grain with steel wool until the table top presents a smooth surface.

10. Sand with 4/0 sandpaper to remove all scratches, sanding in the direction of the grain.

11. After sanding, apply a coat of raw linseed oil and let dry for about thirty minutes, then wipe off surplus oil from the top and let the remaining oil dry for about six hours.

12. Apply a second coat of raw linseed oil, wipe off surplus after thirty minutes and allow top to dry over night.

Other coatings, offered by various manufacturers, provide similar results. These treatments form a protective film that is somewhat more reagent-resistant than the carbonizing process and eliminates the excessive use of water in obtaining the finish. The use of this type of top is advantageous in laboratories occupied by inexperienced persons. Wood tops are not easily damaged and are comparatively easy to recondition without removal from the cabinetwork. Their disadvantage is that they are not fireproof.

For types of laboratory work other than chemistry, wood tops may be finished with varnish or treated with oil. The varnished top usually presents the better appearance; but for physical-testing work or other bench work during which the top is subject to severe abrasion, the oiling process probably gives the more satisfactory results. The oiled surface is easily cleaned with steel wool and a fresh coating of wax or oil may then be applied without that loss of time which may be unavoidable when a varnished top is being reconditioned.

Soapstone, sandstone, and slate provide the basic materials for the natural or quarried types of tops. Soapstone has been used for working surfaces for laboratory tables for a great many years. It is relatively easily worked and, in addition, is fireproof, inert, non-absorbent (maximum 2/10 of 1%), is unaffected by solvents and is resistant to heat, acids and alkalies as used in the laboratory. Without stratification or cleavage planes, it may be machined accurately in any direction without chipping or spalling. Joints, made gas-, germ- or liquid-tight with either tongue-and-groove or splined construction are filled with acid- and alkali-resistant cement, a number of kinds of which are available. Litharge and glycerine is the most commonly used cement. Soapstone is available in two grades to all laboratory equipment manufacturers, contractors and owners. Regular soapstone is commonly used in most types of installations where requirements are not too severe. 25-grade soapstone (hardstone) is several times harder than the regular grade, has a maximum absorption of 1/10 of 1%, is more resistant to abrasion, acids and alkalies, is darker in color and takes a better finish. Construction details are the same for both grades, but because of the difference in hardness, 25-grade costs about 50% more than the regular grade. Both grades of soapstone are frequently dressed with an oil and wax preparation after installation. These formulas may be used for darkening and oiling soapstone:

No. 1

Heat one quart of kerosene and melt into it one pound of paraffin which has been cut into small chunks. After cooling, add two quarts of raw linseed oil and two or three handfuls of lampblack. If the mixture is too thick to spread conveniently, it may be thinned with additional kerosene.

The mixture should be spread on with rough cloths, allowed to oxidize and then rubbed off. A smooth, glossy dark finish is thus obtained.

No. 2

1 quart carbon tetrachloride
1 quart naphtha
Dissolve ½ pound paraffin with ¼ pound lampblack

The above is rubbed on, allowed to stand and then is rubbed dry. This type of dressing is applied several times a year.

The tops are cleaned with an oily rag, which usually takes off any surface marks, and the stonework in general when treated this way appears to have a uniform dark color at all times. Soapstone, like wood, can, when necessary, be sanded or dressed without removal from cabinets.

Sandstone, fully impregnated and subsequently surface-coated with a polymerized furan resin, was first placed in use in 1942. An extremely fine-grained sandstone, free of stratification and veins, is used. Impregnated sandstone tops provide a black, uniform finish in a dull gloss which is easily kept clean. This material is unaffected by solvents and is extremely resistant to alkalies and to most acids. Impregnated sandstone is affected by strong oxidizing agents, such as concentrated nitric acid, concentrated sulfuric acid, and dichromate cleaning solutions, when subjected to them for relatively long periods of time. While this material provides adequate resistance to heat under laboratory conditions, it is recommended that insulation be provided where highly localized heat or extreme cold, such as is produced by quantities of dry ice, is applied over substantial periods of time. Impregnated sandstone has good resistance to abrasion, is strong mechanically, may be fabricated to meet most requirements, and may be furnished in quite large sizes. No maintenance is required other than occasional cleaning with soap and water, and the resulting working surface is free of oil.

Slate is quite resistant, but its laminated structure tends to produce spalling or flaking of the surface unless great care is used in its selection. In recent years it has most often been used for tops for tables supporting balances or other types of delicate apparatus. Slate tops, like soapstone or sandstone tops, usually require the employment of stonesetters for installation.

There are two general types of composition tops: cement asbestos and "Masonite". Cement asbestos may be impregnated with resinous materials. Both materials are supplied with or without high reagent-resistant surface treatments. The surface may also be waxed. However, waxing does not materially increase solvent resistance, whereas other types of surface treatment do offer high solvent as well as reagent resistance. The surface treatment can be damaged by excessive exposure to heat, chemicals or physical abrasion. Refinishing procedures are available from the manufacturers, and maintenance is not an extremely difficult process. Besides their inertness, these tops have the advantage of good appearance and comparatively easy machining characteristics so that alterations are easily made. The material is available in sizes up to 4 feet by 8 feet; consequently working surfaces can be supplied with few joints. The impregnated material is usually known as black acid-resisting composition and the untreated material as asbestos stone composition.

Solid pressed wood or "Masonite" tops are constructed of two or more layers of "Masonite" glued together to obtain the desired thickness and then given surface treatments similar to those used for the cement asbestos material. The surface treatments cannot be baked at as high temperatures as those applied to the previously mentioned tops and are therefore not as resistant. The material is not as hard as cement asbestos, has more resiliency and approaches wood tops in physical characteristics. The sheets come in large sizes and the tops may be supplied with few joints. Alkalies are destructive to this type of top once the treated surface is broken. This material is often referred to as black acid-resisting composition.

"Masonite" tops may also be constructed by using plywood cores between ¼ inch to ⅜ inch thick sheets of "Masonite". This type is somewhat less expensive, but the surface finish is not quite as good as on the solid tops since a lower baking temperature must be used.

The problem of sealing against moisture at openings for sinks and service piping is also introduced. It is, however, good top for physical and biology laboratory tables, for balance tables and writing surfaces.

A rubber or linoleum surface with a metal or wood base may be used advantageously in specific applications, but care must be taken to seal against moisture at sink openings. This can be done. Rubber and linoleum are probably more satisfactory for physical applications than for chemical.

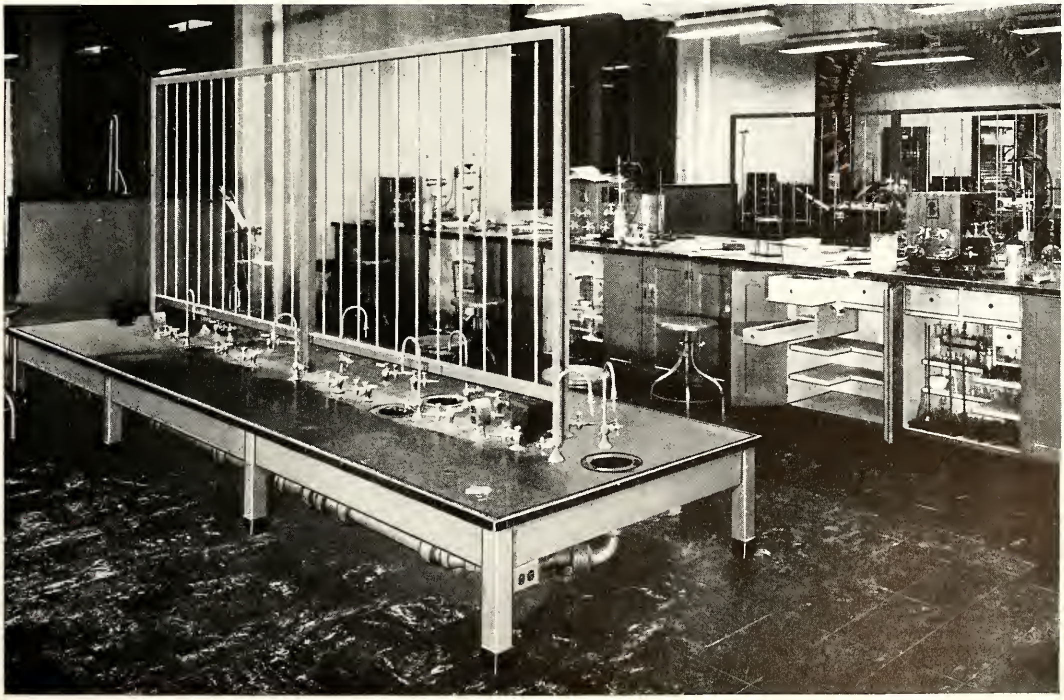
Metal tops—stainless steel, "Monel", lead, galvanized iron, zinc and steel—have definite applications. Galvanized iron, zinc, and steel are more applicable to physical work. Stainless steel, "Monel", and lead are quite satisfactory for some chemical applications. Lead, zinc, and thin metal tops are usually furnished over a wood or other metal base. Stainless steel, "Monel", and steel are furnished in either heavy or light gauges. The heavy gauges are usually reinforced on the underside with channels or boxing, and, often, sound-deadening coating is also specified. When metal tops are shipped in sections, field joints can be burned or soldered if necessary, although, normally, a good butt joint, properly sealed, is quite satisfactory.

Structural glass is applicable to definite laboratory uses. Sections of structural glass are used at titration stations, or as working surfaces for titration tables and balance tables. They may be used in ink and color laboratories as "smear plates". Care should be taken to design the working surface so that replacement of structural glass is easily accomplished.

Formerly, ceramic tile was used for working surfaces, but the excessive cost of this type of construction, together with the availability of newer materials with greater versatility, has over-balanced any possible advantage that tile tops may once have offered.

In considering the kind of top from the standpoint of use, the best chemical tabletops are generally thought to be wood with black acid-resistant finish, soapstone, sandstone, composition stone, stainless steel, rubber, "Monel", or lead. The kinds of tops used for physics tables are wood with black acid-resistant or other finish, any of the metal tops (except possibly lead), composition wood fiber, rubber or linoleum. Utility and accessory tables, including balance, spectrograph, and physical-testing apparatus tables, and also office reading

Figure I.9 In the foreground is a table arrangement for supporting pre-pilot-plant equipment. Complete sets of services, including waste cup sinks, are provided. The wall table in the background shows turret-type fixture mounting and indicates how the various pieces of apparatus may be stored.



tables and desks use tops of composition wood fiber, linoleum, varnished wood, structural glass, and soapstone.

Benches for physical testing should have wood or metal tops. Whenever high heat is involved, a metal or asbestos-board surface is recommended. A V-shaped drip groove should be provided near the front edge on the underside of any top on which liquids might be spilled.

Cabinetwork for laboratory tables may be made of wood or metal.[*] Wood cabinetwork should be constructed with hardwood exteriors and with a minimum of softwood panels for cupboard backs and interior panels. Either wood of open grain, such as oak, or hardwoods of close grain, as birch or maple, are accepted as standard.

Metal cabinetwork is usually made of furniture steel,[†] although stainless steel and aluminum are sometimes specified for special applications.

Considerable work has been done to develop finishes for both wood and metal cabinetwork, and constant effort and research seek to improve these coatings. The industry as a whole is in a position to furnish either metal or wood equipment, finished with coatings that resist the rigors of laboratory exposure. These finishes require careful control and application, and add materially to the resistance of the cabinetwork to the corrosive effects common to laboratory accidents, such as spillage, fuming and excessive moisture conditions.

Cabinetwork serves two purposes: first, it acts as a support for the working surfaces and the various accessories, such as sinks, baths, and hot plates, as well as housing for service and waste lines; secondly, it is used as a storage space. It is desirable to have adequate cupboard and drawer storage at the technician's work position.

The various kinds of cabinetwork may be classified as:

A. Open frame
B. Cabinet work at sinks and hoods
C. Cupboards and drawers
D. Drying cabinets and ventilated storage.

Open-frame tables are the least expensive type of cabinet work; these also make it possible for technicians to sit while working. A certain number of knee spaces are usually incorporated in drawer and cupboard arrangements. Knee-space rails that carry drawers usually have a minimum height of 4½ inches. In positions where the work must be kept low, as in microscopy, it is advisable to dispense with drawers and to use very narrow rails at knee spaces. Drawers must also be omitted from the apron rails at places where sinks and other recessed equipment, such as hot plates and cooling pans, are placed.

The number of possible arrangements of cupboards and drawers is legion. However, in the interests of economy and the solution of production problems, the industry has found that most storage problems can be satisfactorily met with a limited number of arrangements. The line drawings shown in figures I.10 to I.14 are of cabinet arrangements which are available as stock items from the industry as a whole, and, if the cabinet requirements are kept within this selection, both the cost and delivery will be more favorable. These cabinet units are built in various lengths from 18 to 48 inches in approximately 6-inch increments, and by proper selection of units practically any length table can be assembled. This is especially true if odd measurements are filled by knee spaces. The industry has also standardized height at approximately 36 to 37 inches for "standing" work and at 29 to 31 inches, usually 30 inches, for "sitting" work.

A few units may need to vary materially from these measurements, such as special microscope tables, titration units, or special electrical-analysis equipment tables. These units can usually be open-frame tables, and the special heights can be obtained without excessive alteration of standard practice.

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[*] The subject of the relative merits of metal and wood furniture is a somewhat controversial one between the manufacturers of the two types. It is admitted by all that the initial baked-on finish which may be applied to metal is more chemically resistant and durable than any finish at present available for wood. Those favoring metal furniture contend that some of the new air-dry resin finishes provide cheaper refinishing of metal than of wood since it is only necessary that any rust spots be removed, the damaged finish be lightly sanded and the surface then be spray coated with the new lacquer. Furthermore, if the metal surface is bonderized or otherwise protected, rust is unlikely even if the finish has been strongly attacked. It is claimed that this air-dry refinishing lacquer is as chemically resistant as any now known finish for wood. It is also pointed out by the metal furniture proponents that the refinishing of wood involves considerably more removal of the old finish and preparation of surface for the new finish than is the case with metal.

Wood furniture is of course combustible, but it affords better protection for volatile material stored in cupboards during a short hot laboratory fire than does metal. It has the advantages of lighter weight, warmer feel, and the natural beauty of the wood grain exposed by clear chemically resistant synthetic finishes. If the finish is accidentally removed the wood does not rust and deteriorate as does unprotected steel. Wood, however, is to some extent subject to damage owing to the absorption of moisture if the finished surface is removed. Wood furniture may have removable drawer fronts which are easily replaced if damaged.

In summation, the manufacturers of wood furniture claim the following advantages:

1) Natural warmth and beauty with chemically resistant clear or colored finishes.
2) Quiet operation.
3) Easy to maintain.
4) Wood is naturally resistant to chemicals.
5) Adaptable to alterations.
6) Has natural insulating qualities protecting contents against minor fires.

On the other hand, metal furniture manufacturers claim that metal furniture is:

1) Structurally strong.
2) Fireproof—will not support combustion.
3) Has a high ratio of usable space to floor space occupied.
4) Permits high temperature baking enamels developing maximum chemical resistance.
5) Is non-absorbent to moisture, fumes or liquids.
6) Provides easy operation of moving parts.

[†] Metal furniture should have some type of protective coating underlying the finish. Steel coated with lead, zinc or other metals is excellent but great care must be exercised during manufacture to assure that the coating is kept intact. Sheared edges must be recoated and surface coatings removed by grinding during assembly must be carefully repaired.

"Bonderite," a product which converts metallic surfaces to a nonmetallic phosphate coating, is employed by many metal furniture manufacturers to improve paint adhesion and resistance to corrosion. It has the advantage in that the "Bonderite" coating is applied after fabricating is completed, thus preventing the spread of corrosion from uncoated edges. —EDITOR

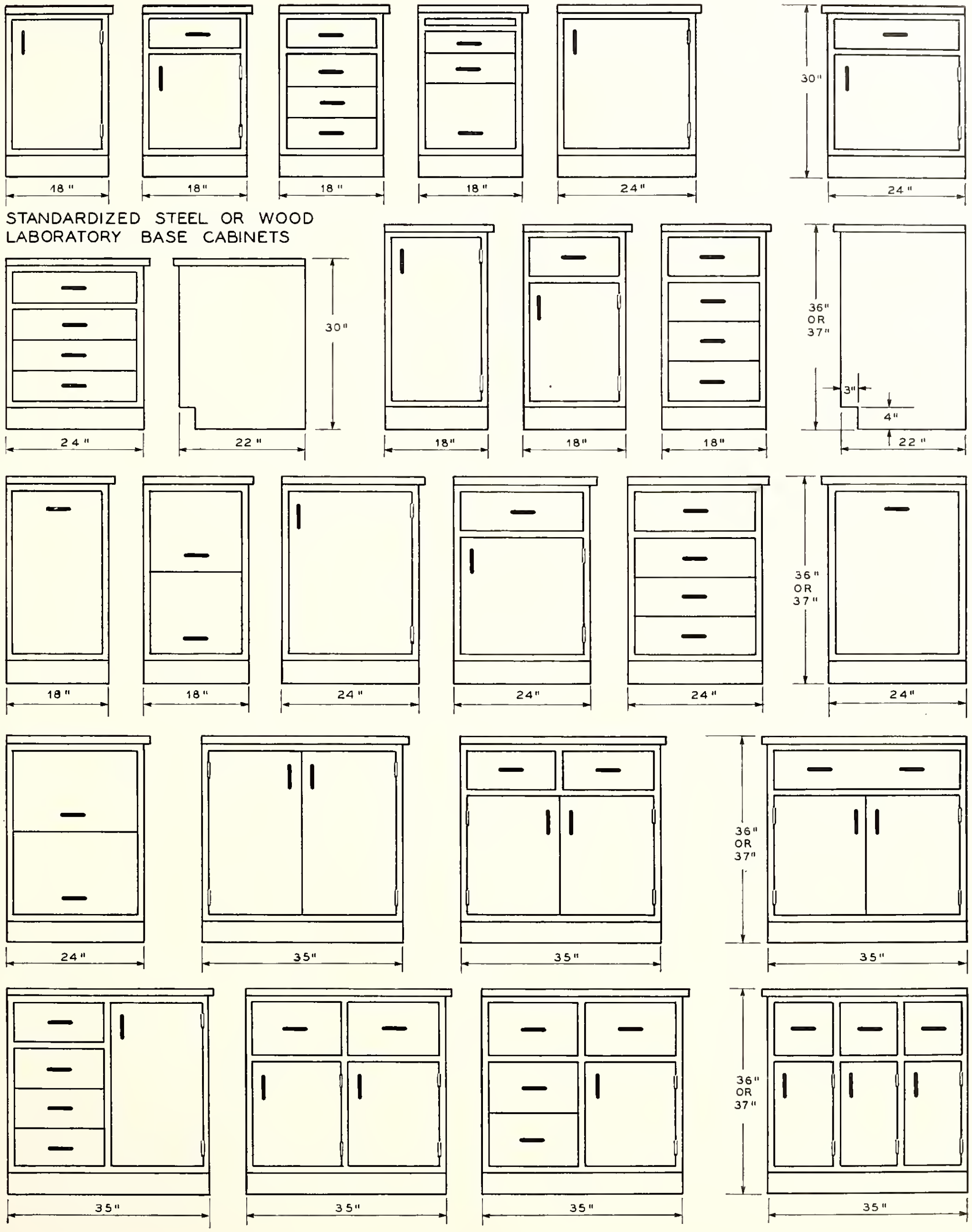


Figure 1.10 Standardized laboratory furniture units.

Cupboards are fitted with removable shelves which are adjustable in steps of approximately 1 inch. This provides for storage of apparatus of unusual sizes.

Base cabinets are furnished by the industry with a toe space approximately 4 inches high by 3 inches deep. In laboratory installations, when the equipment is set on terrazzo or other type of structural base, it is advisable to design this building detail so that standard base units can be installed by merely omitting the standard cabinet toe space. This enables the manufacturer to furnish such equipment from stock and makes unnecessary the buying of special cabinets to meet building conditions.

Cabinet unit depths are standardized at 22 inches. This enables over-all widths for free-standing tables to vary from 48 inches up and to provide space for center-drain troughs, pipe space, and drain-line space entirely behind the cabinetwork. The preferred width of the standing tables is 54 inches, although in student laboratories this width may be reduced to 48 inches in the interest of placing as many tables as possible in a given laboratory. However, 54 inches is a better width

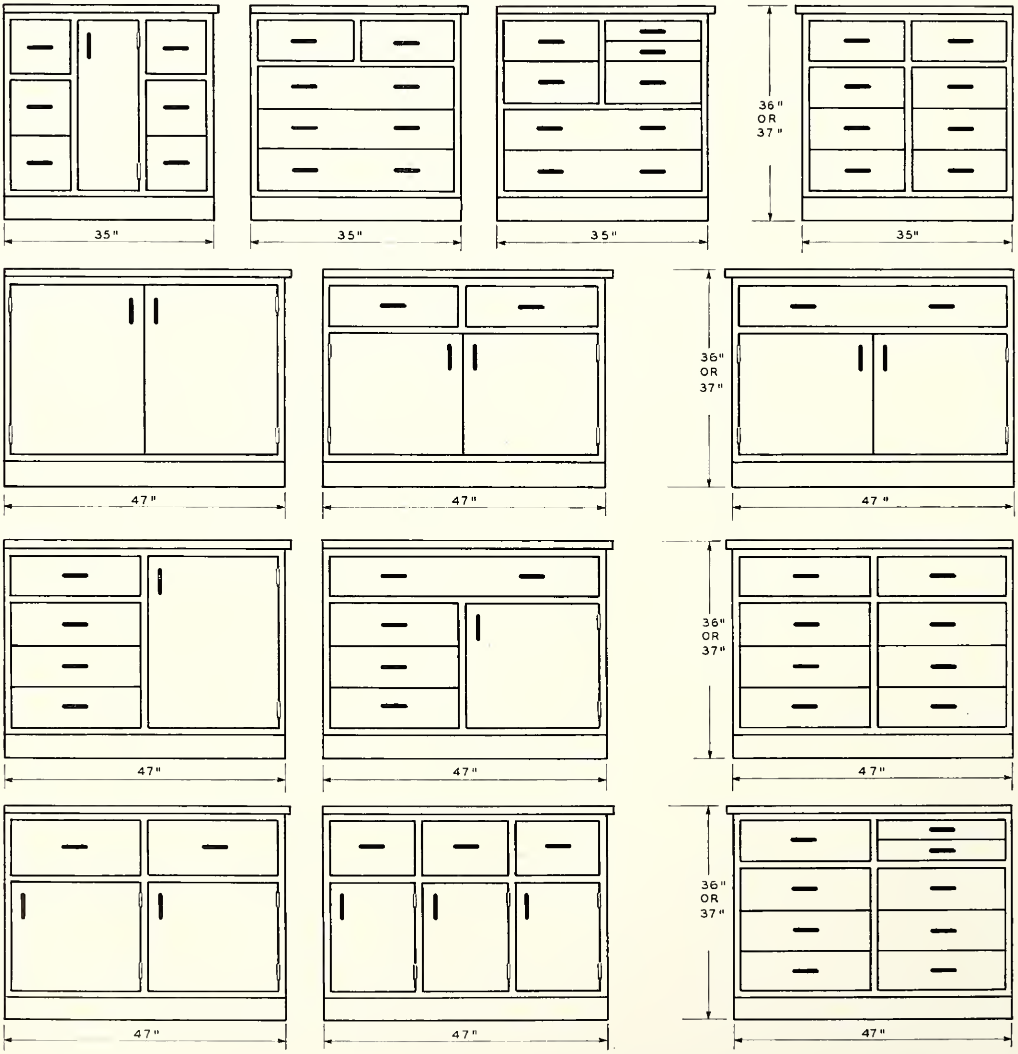


Figure 1.11 Standardized laboratory furniture units.

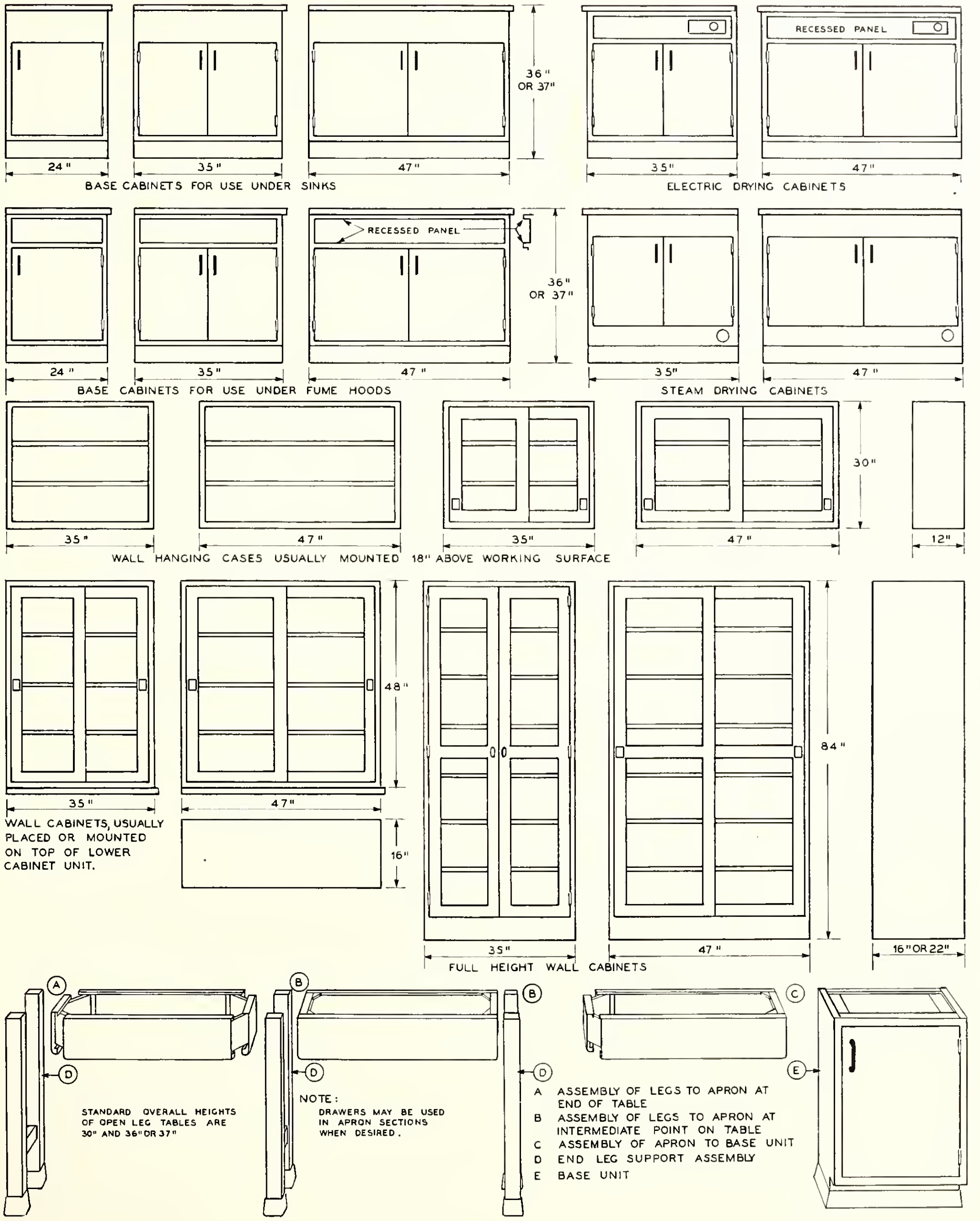
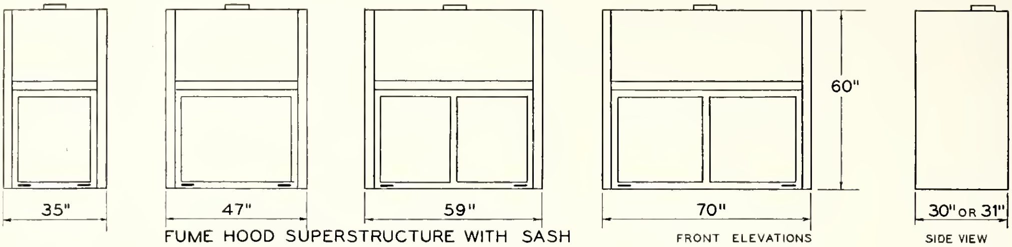
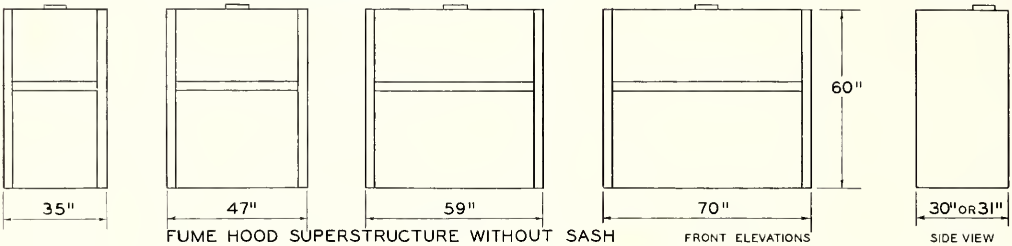

24"
35"
47"
36" OR 37"
BASE CABINETS FOR USE UNDER SINKS
RECESSED PANEL
35"
47"
ELECTRIC DRYING CABINETS
RECESSED PANEL
24"
35"
47"
36" OR 37"
BASE CABINETS FOR USE UNDER FUME HOODS
35"
47"
STEAM DRYING CABINETS
35"
47"
35"
47"
30"
12"
WALL HANGING CASES USUALLY MOUNTED 18" ABOVE WORKING SURFACE
48"
35"
47"
16"
WALL CABINETS, USUALLY PLACED OR MOUNTED ON TOP OF LOWER CABINET UNIT.
84"
35"
47"
16" OR 22"
FULL HEIGHT WALL CABINETS
A
B
B
C
D
D
D
E
STANDARD OVERALL HEIGHTS OF OPEN LEG TABLES ARE 30" AND 36" OR 37"
NOTE: DRAWERS MAY BE USED IN APRON SECTIONS WHEN DESIRED.
A ASSEMBLY OF LEGS TO APRON AT END OF TABLE
B ASSEMBLY OF LEGS TO APRON AT INTERMEDIATE POINT ON TABLE
C ASSEMBLY OF APRON TO BASE UNIT
D END LEG SUPPORT ASSEMBLY
E BASE UNIT

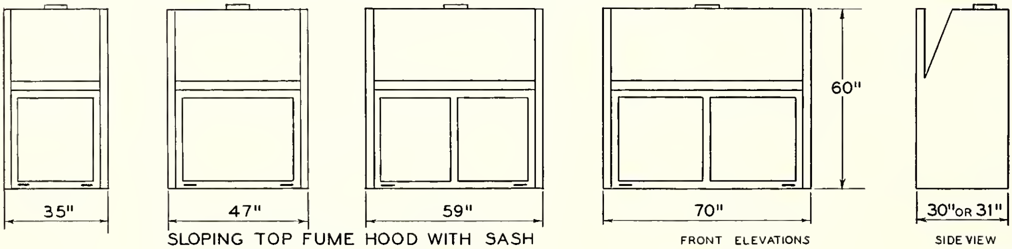
Figure 1 12 Standardized laboratory furniture units.



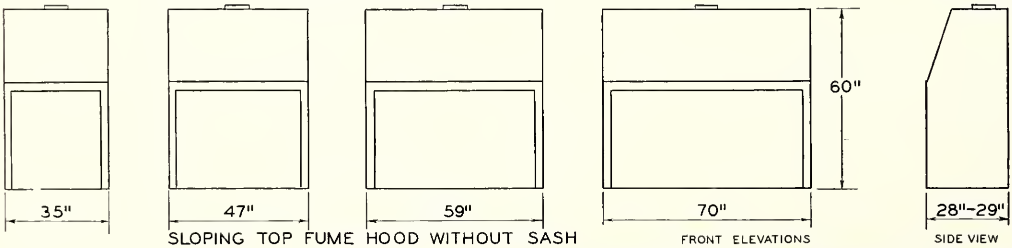
FUME HOOD SUPERSTRUCTURE WITH SASH



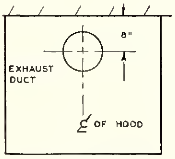
FUME HOOD SUPERSTRUCTURE WITHOUT SASH



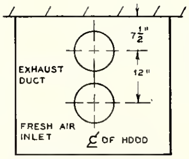
SLOPING TOP FUME HOOD WITH SASH



SLOPING TOP FUME HOOD WITHOUT SASH



ROUGHING IN LAYOUT FOR LOCATING EXHAUST DUCTS IN FUME HOOD TOPS.



ROUGHING IN LAYOUT FOR EXHAUST & INLET DUCTS FOR SELF-PURGING HOODS IN AIRCONDITIONED LABORATORIES.

THESE FUME DUCT LAYOUTS APPLY ONLY WHERE MINIMUM MEASUREMENTS ARE HELD AS TO CEILING HEIGHTS, AND OTHER BUILDING CONDITIONS DO NOT INTERFERE.

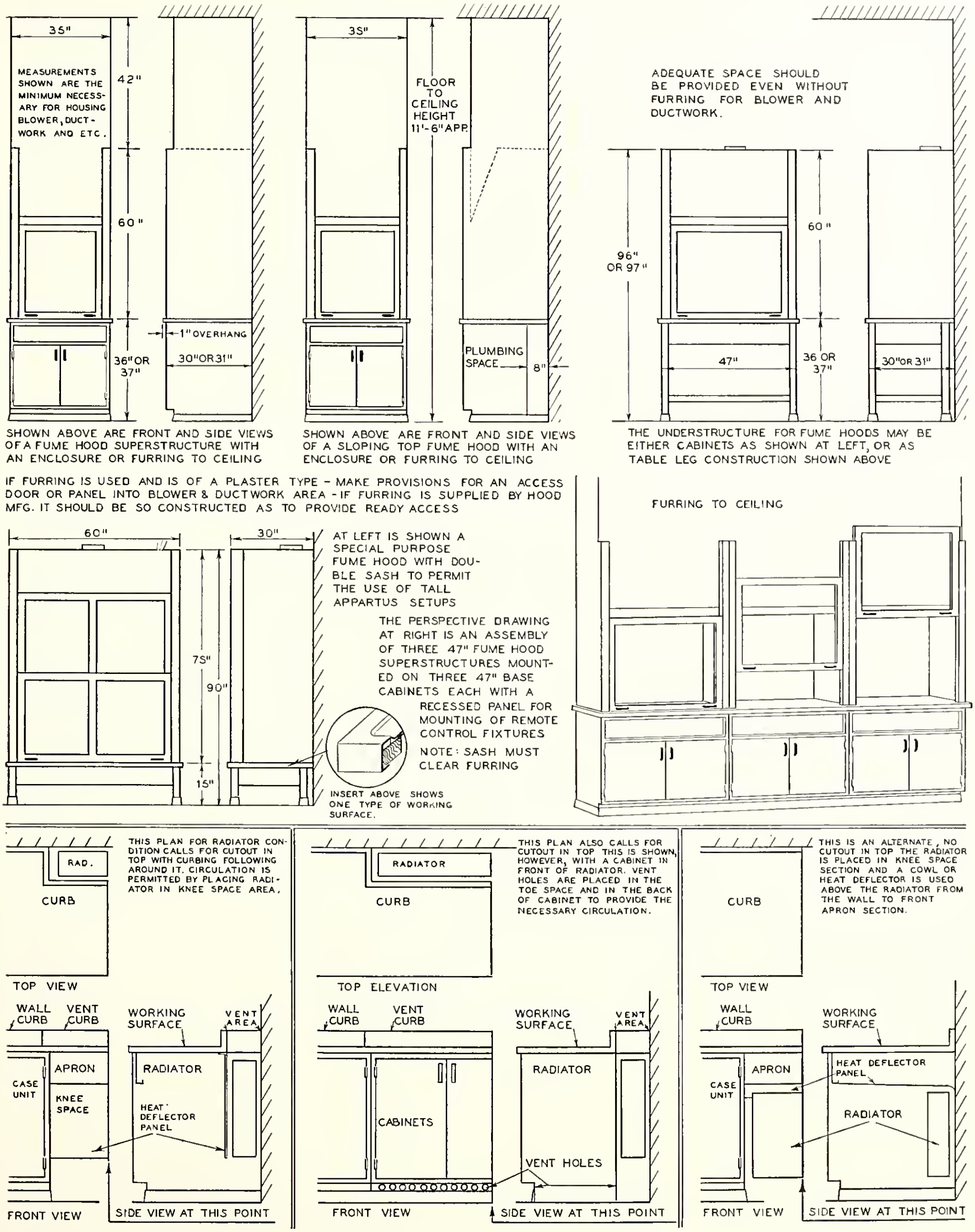
EXHAUST DUCT SIZES WILL VARY FROM 7" TO 11" IN DIAMETER. IN GENERAL, THE FOLLOWING AIR VELOCITIES ACROSS THE FACE OF THE HOOD SHOULD BE USED.

SCHOOLS	50 TO 60 LIN. FT. PER. MIN.
COLLEGES	60 TO 80 LIN. FT. PER. MIN.
INDUSTRIAL	80 TO 100 LIN. FT. PER. MIN.

AIR VELOCITIES IN DUCTS SHOULD NOT EXCEED 1500 L.F.M. UNLESS INSTALLATION CONDITIONS MAKE DUCT SYSTEMS OPERATING AT HIGHER VELOCITIES NECESSARY. VELOCITIES EXCEEDING 2000 L.F.M. MAY CAUSE EXCESSIVE NOISE.

SELF-PURGING HOODS REQUIRE AN OUTSIDE AIR INLET AS WELL AS AN EXHAUST DUCT. INLET DUCT SHOULD BE LARGE ENOUGH TO HANDLE UP TO 80% OF TOTAL AIR TO BE EXHAUSTED THROUGH HOOD.

Figure 1.13 Standardized laboratory fume hoods.



MEASUREMENTS SHOWN ARE THE MINIMUM NECESSARY FOR HOUSING BLOWER, DUCTWORK AND ETC.

SHOWN ABOVE ARE FRONT AND SIDE VIEWS OF A FUME HOOD SUPERSTRUCTURE WITH AN ENCLOSURE OR FURRING TO CEILING

SHOWN ABOVE ARE FRONT AND SIDE VIEWS OF A SLOPING TOP FUME HOOD WITH AN ENCLOSURE OR FURRING TO CEILING

ADEQUATE SPACE SHOULD BE PROVIDED EVEN WITHOUT FURRING FOR BLOWER AND DUCTWORK.

THE UNDERSTRUCTURE FOR FUME HOODS MAY BE EITHER CABINETS AS SHOWN AT LEFT, OR AS TABLE LEG CONSTRUCTION SHOWN ABOVE

IF FURRING IS USED AND IS OF A PLASTER TYPE – MAKE PROVISIONS FOR AN ACCESS DOOR OR PANEL INTO BLOWER & DUCTWORK AREA – IF FURRING IS SUPPLIED BY HOOD MFG. IT SHOULD BE SO CONSTRUCTED AS TO PROVIDE READY ACCESS

AT LEFT IS SHOWN A SPECIAL PURPOSE FUME HOOD WITH DOUBLE SASH TO PERMIT THE USE OF TALL APPARTUS SETUPS

THE PERSPECTIVE DRAWING AT RIGHT IS AN ASSEMBLY OF THREE 47" FUME HOOD SUPERSTRUCTURES MOUNTED ON THREE 47" BASE CABINETS EACH WITH A RECESSED PANEL FOR MOUNTING OF REMOTE CONTROL FIXTURES

NOTE: SASH MUST CLEAR FURRING

INSERT ABOVE SHOWS ONE TYPE OF WORKING SURFACE.

THIS PLAN FOR RADIATOR CONDITION CALLS FOR CUTOUT IN TOP WITH CURBING FOLLOWING AROUND IT. CIRCULATION IS PERMITTED BY PLACING RADIATOR IN KNEE SPACE AREA.

THIS PLAN ALSO CALLS FOR CUTOUT IN TOP THIS IS SHOWN, HOWEVER, WITH A CABINET IN FRONT OF RADIATOR. VENT HOLES ARE PLACED IN THE TOE SPACE AND IN THE BACK OF CABINET TO PROVIDE THE NECESSARY CIRCULATION.

THIS IS AN ALTERNATE, NO CUTOUT IN TOP THE RADIATOR IS PLACED IN KNEE SPACE SECTION AND A COWL OR HEAT DEFLECTOR IS USED ABOVE THE RADIATOR FROM THE WALL TO FRONT APRON SECTION.

Figure I.14 Standardized laboratory fume hoods.

and should be used wherever possible. Industrial tables are often 60 inches wide. These various widths of table are obtainable by using standard base cabinets and varying the dimensions of the plumbing space behind the cabinets.

Wall tables without water connections and sinks are usually 24 inches wide. When water connections and sinks are involved the minimum is usually 30 inches, unless the roughing-in for sink and water can be located immediately below the sink position. Wall tables with troughs are usually 30 inches wide as a minimum (see figure I.15).

The plumbing space to be provided behind the cabinets of wall tables and between the cabinets in free-standing double tables should be at least 7 inches wide. This space is adequate if the ordinary service and waste lines are properly designed. Traps can also be accommodated in this space. If excessive or unusual services are required, the space for service lines should be increased (see figures I.16 to I.18). For ready access to traps and service lines, it is a good idea to provide for the easy removal of one or more cabinets or to use cupboards with removable backs.

Cupboard cabinets, instead of those with drawers, are necessary at sink positions because of the necessity of housing and supporting the sink. Well designed cabinetwork provides for adequate sink supports and does not depend on supporting the sink by means of clips or hangers fastened to the underside of the working surface.

Even though the best of available materials is used and the installation is done in the most workmanlike manner, replacements and repairs must often be made. Laboratory demands on equipment and accessories are severe under the best of conditions, and provisions for making replacements and repairs as well as for periodic inspections are an essential part of design and construction.

Cabinetwork below the working surface of fume hoods should be made up of cupboard units without drawers, if drawer storage can be provided elsewhere. The apron rail of a hood base needs to be extra wide. Sinks, baths, and hot plates are essential accessories in most hoods (see figure I.7).

As a matter of safety, services in hoods should be remotely controlled, even though regular deck- or curb-mounted fixtures are used. The remote controls are mounted on the wide rail in front. Often electrical outlets, motor and light switches are also most conveniently mounted on the same wide rail. When recessed hot plates are incorporated in the hood working surface, the controls are most conveniently located in this rail.

Drying compartments and storage for fuming chemi-

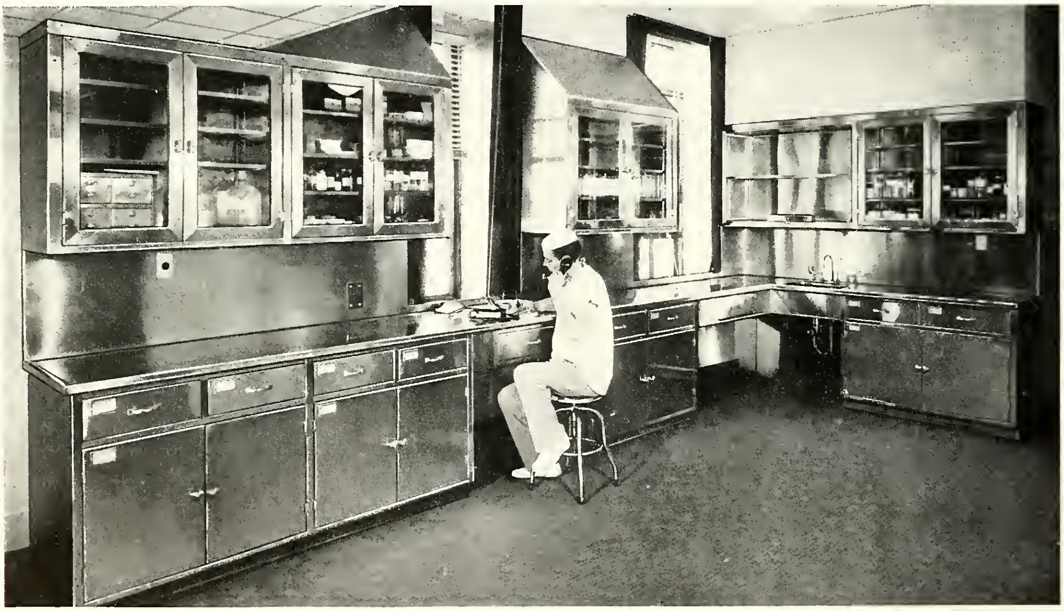


Figure I.15 Knee-space openings in a wall table and an arrangement for placing a sink in a 24-inch wide wall table. This is possible because the waste and the service outlets are immediately below the sink position. This figure also shows methods of supporting upper storage cases on the wall.

cals are logically located in hood base cabinets, since the cupboard can easily be vented into the superstructure.

In attempts to make laboratory layouts more flexible, especially for research, the so-called island arrangements have been developed. The island in its basic form is either a wall shelf or a free-standing narrow table usually 6 inches to 8 inches wide. It carries all the fixtures for services, such as gas, air, vacuum, and electricity, and frequently is equipped with water faucets and cup sinks. The framework supporting the island top is arranged with pipe clips to carry the horizontal service and waste lines. Table units with individual working surfaces are moved to this island shelf to form whatever type of cupboard and drawer storage arrangement is required. When there are no table units in front of the island shelf, a cover panel may be provided to conceal the pipe lines and the supports. In chemical laboratories a difficulty inherent in this arrangement is the necessity of having an adequate seal between the edges of the island shelf and the movable tabletop section, and between tabletop sections (see figures I.16 to I.18).

Table units must be carefully leveled to meet the island shelf. Floors are usually uneven so care must be taken to have everything in perfect alignment. One way to overcome this difficulty is to provide adjusting devices (leveling screws) on the bottoms of the cabinet corners. Work surfaces of each unit can then be made to meet the exact level of the island. In this type of installation it is necessary to have the island supports carefully leveled. One other point to consider in such installations is that cabinetwork and top dimensions cannot be held to extreme dimension tolerances. Consequently, the working surface should be furnished with a slight overhang on the ends and some type of scribe or filler strips provided to make a finished installation where cabinet units do not exactly meet at the front stiles.

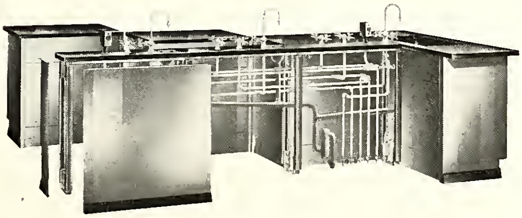


Figure I.16

Where large sinks are a part of island arrangements, the sinks and cabinets are permanently installed, and only the units on either side are removable.

Another quite satisfactory arrangement is to have the entire working surface supported at regular intervals by leveling screw equipped uprights. The cabinets are supported on horizontal frames attached to the uprights and are easily arranged and rearranged below the tops.

Islands may also carry tunnel arrangements, and various types of cup sinks can be mounted on the vertical face of the tunnel. If the fixtures are also mounted on the vertical face of the tunnel, the top of the tunnel may be used as a reagent rack (see figure I.17).

Another method is to carry service and drain lines in partition walls (see page 10). The structural members are metal, punched to allow the lines to pass. With this method, capped or plugged tees may be provided along the wall for later fixture installation. This procedure works well for the streamlined service lines, but the drain lines sometimes offer problems.

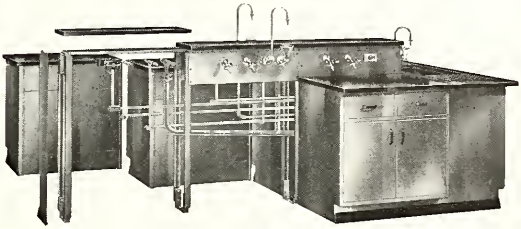


Figure I.17

Figure I.16 A method of supporting piping of all kinds in a plumbing island. The island is provided with a top working surface which carries all plumbing and electrical fixtures, including cup drains, a cold water service utilizing gooseneck outlets, gas, air, and vacuum fixtures, and electricity. Note also the method by which cabinetwork units and the large, end, wash sink are placed against the plumbing island to form a continuous table after all of the mechanical services have been connected.

Figure I.17 A desk built up around a plumbing island as in figure I.16, but with the plumbing island raised to provide a reagent rack and with mechanical services mounted in the raised ledge provided by the high island.

Figure I.18 Another method of mounting service and waste lines behind cabinetwork and below a fixed shelf. This is a service rack or island.

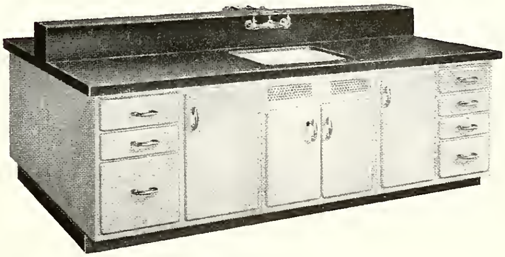


Figure I.18

Adequate storage space, aside from that furnished at the worktables, makes for better working conditions and good housekeeping. Display cases, in which certain products are properly arranged for viewing, help to vitalize laboratory work and are often timesavers as well. Bulk storage is best taken care of in a stockroom, and, usually, open shelving is adequate except when excessive dust conditions prevail. The use of closed shelving, or of cases with swinging or sliding doors, will often save enough in spillage and damage to warrant the extra expense. Display cases should have locks. Open shelving storage is advised when frequent access is necessary. Cases containing less frequently used materials should have doors, but sliding doors should not be used in full height cases 3 feet or less in width.

It is often possible to use batteries of storage cases placed back to back as divisions in large laboratory rooms. In this way adequate storage space is provided and yet the advantages of semi-private laboratory spaces are obtained. Cases more than 7 feet high, unless a ladder system is incorporated, are only useful for the storage of infrequently used articles.

SINKS AND TROUGHS (MATERIALS)

Like working surfaces, sinks and troughs in laboratory tables are subject to widely varying use, and, consequently, several materials have been developed from which they may be made.

Sinks are subject to more severe service than working surfaces, which, normally, are quickly cleaned when corrosive materials are spilled on them. In the case of sinks, active chemicals are often dumped into them and left to work their damage without adequate flushing. The traps for such sinks, also, must withstand destructive action since very active chemicals may remain in the traps for some time before they are flushed away. For this reason, an auxiliary water connection is often provided, which continually supplies flushing water. This faucet is often placed at the upper end of the trough and so flushes both the trough and end sink. Such an arrangement is especially valuable on student tables.

Trained personnel can ordinarily be depended upon to flush away corrosive materials. There are routine procedures, however, such as perchloric acid determinations, when an adequate and continuous flushing of filtrate is advisable.

Many of the materials available for working surfaces are used for sinks. However, because sinks are subject to more abuse than tops, sink materials are usually selected for more adequate resistance than may be specified for working surfaces.

Soapstone, either regular or hard grade, and sandstone, properly impregnated, are the usual natural materials. The sinks are constructed of slabs, and joints are made liquid-tight with tongue and groove and concealed bolt and nut construction. Sink bottoms may be dished to drain and the corners may be coved. This type of construction adds measurably to the ease of cleaning and thoroughly flushing sinks.

Ceramic-ware sinks have the advantage of being of one-piece construction. Since they are a manufactured product, the body material is usually more uniform in composition than natural materials. Ceramic-ware or stoneware sinks are frequently not as accurately dimensioned as other sinks, since they are subject to distortion in the firing process. Ceramic sinks may be more subject to breakage from physical and thermal shock than other types although ceramic-ware sinks with very high thermal shock resistance are available. Cast ceramic-ware sinks can be had in limited sizes. Cast sinks are usually more accurately sized and uniform in shape than those constructed from mud slabs. These sinks present a good appearance and, being non-porous, are easily cleaned. Ordinary solid porcelain sinks are not commonly specified for heavy duty chemical work since the body under the surface glaze is usually more porous and absorbent than is ceramic-ware. Porcelain on iron or steel is subject to the same weakness in that, if the porcelain becomes damaged, the iron is exposed to corrosive action.

Metal or metal-lined sinks are best from the standpoint of physical damage and heat-and-cold resistance. Lead lining is most inert chemically but suffers from contact with mercury. Stainless steels are quite resistant to most reagents and, if kept flushed, stand up well. These sinks are also easy to keep clean and are preferred in food, biochemical and other laboratories in which cleanliness and neat appearance are essential. "Monel" sinks are quite resistant to chemicals but tend to darken unless frequently polished. "Duriron" and "Corrosiron", high silicon cast irons, are among the most inert materials available. They are, however, subject to breakage when under physical strain.

Wood tanks and sinks, usually made of cypress, are excellent when kept continually filled; but if allowed to dry out, may leak badly until the wood becomes thoroughly soaked and swells tight. Wood tanks coated with various materials, such as asphaltum and other paint, are subject to peeling once moisture gets into the wood base either from the inside or the outside.

Sinks may also be made of a number of inert alloys other than the more common stainless steels and "Monel", as well as various nonmetal compounds. These materials have varying acid, caustic, and solvent resistance characteristics, and care should be taken to select the proper material for the purpose required.

Sinks and troughs may be classified as to use. Catch basin or cup sinks are small hemispherical or oval sinks of chemical stoneware, lead or "Duriron". These sinks may be mounted flush in the tabletop, and some models are available for mounting on the vertical face of a tunnel. They often take the place of troughs and can be placed below water cocks mounted in bottle racks to take care of drip, and they serve as receptacles for water from condensers, vacuum pumps, etc. They are convenient as small disposal sinks since they take up little room and may be placed at frequent intervals thus saving frequent trips to larger sinks. Local plumbing codes requiring venting of waste lines and outlets

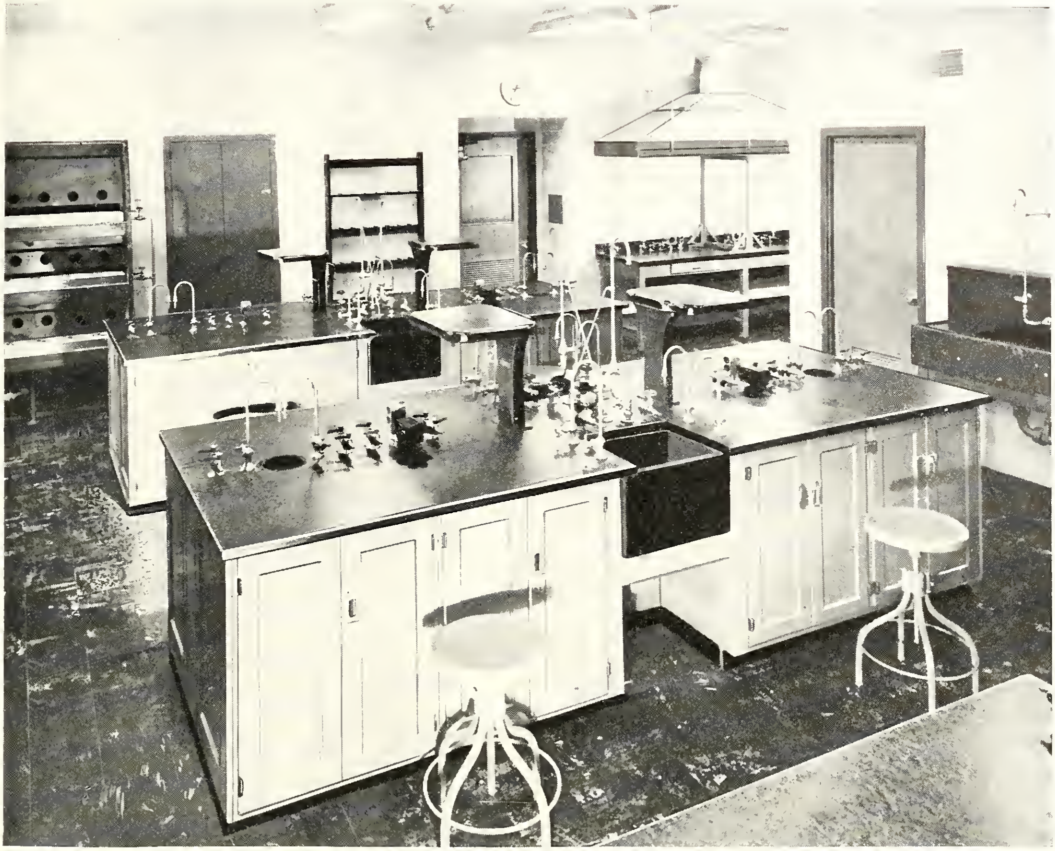


Figure I.19 This indicates the necessity of providing many component parts required for a complete table. Large disposal sinks are mounted under sections of the top. Cup sinks are shown at either end of the table, both types of sinks are equipped with gooseneck faucets. Note the extremely high faucets at the disposal sinks in the table and also at the wash sink at the right wall. This cut also shows the canopy hood at the rear right mounted over a worktable. Table type hoods are displayed on the center tables. Note the Kjeldahl unit against the rear wall at the left. This also illustrates turret-type fixtures, including electrical outlets.

may present a problem when a number of cup sinks are involved. Usually a gooseneck faucet is used with this type of sink, although other types of outlets are often located at cup sinks, such as angle hose connection steam and water cocks (see figures I.17 to I.19).

Wash sinks may be located either at the ends of work tables or as separate sinks apart from the tables. Often they are located in a separate room designed especially for the washing and storage of glassware and related equipment. Under such an arrangement, carts or movable tables for glassware are made a part of the laboratory equipment. The carts are often equipped with movable trays to carry both dirty and clean glassware. The sink itself is often a double compartment unit with a drainboard on one or both ends, and is usually equipped with a swing-spout, hot-and-cold mixing faucet. Often a high gooseneck fixture is advisable for flushing long and deep pieces, such as condenser tubes, tall graduates, and other such pieces (see figures I.8, I.16, I.17 and I.19).

A large pegboard is sometimes located above the drainboards and may extend the full length of the sink. This is convenient for hanging glassware to drain after rinsing. Often distilled water is made available at wash sinks for a final rinse. Air and some type of warm plate are useful in speeding up the final drying. A drying cabinet supplied with warm moving air forms an important unit in the washroom equipment. This may be set up below a hood superstructure or form a unit of its own.

Wash sinks are usually soapstone or lead-lined tanks and may be equipped with bottle-washing sprays or jets and motor-driven brushes. Lead-lined sinks are less damaging to glassware, as far as chipping and breaking are concerned, than are other types. Rubber mats in the bottoms of sinks and on drainboards are an added protection to glassware. Chemical stoneware is possibly more resistant to cleaning solutions used in washing glassware, and for this reason the drainboards may be of this material. If care is taken to rinse the ware thoroughly before it is placed on the drainboards, soapstone and the heavy-duty composition materials are quite satisfactory.

Drainboards are usually grooved. If the grooving is deeper at the open ends, the boards need not be pitched. Flat boards overcome the tendency of inverted articles to creep.

For extra-heavy-duty work a stainless steel cap may be used over the front edge of the sink. If this stainless strip is properly designed, it may easily be removed and replaced as necessity requires.

If heating of the cleaning solution is required, probably the best plan is to use a tank made of the proper alloy steel and to place it in a water bath which may be heated by steam or electricity. Usually it is sufficient to place the cleaning solution in the container to be cleaned and heated. If hot chromic acid is being used, provision should be made for taking care of fumes.

The fume-disposal problem is best solved by installing the wash sink in a standard hood superstructure. A preliminary rinse tank may be placed beside the hot solution compartment; and if warm water is used, the glassware may be given a quick rinse and then removed to an outside rinse bath without excessive dripping. This method avoids the necessity of a very large hood and also removes the cleaned articles from the fumes. A canopy-type hood should not be used over a chromic acid bath, since there is too much opportunity for the fumes to escape into the room, unless excessive draft is used (see figure I.7).

Waste disposal sinks are large sinks placed in the working surface or at the end of the table. They may also serve as wash sinks and as cooling tanks; if for the latter purpose, some type of stopper or standing overflow is provided. Also the tray plug opening is best located in one corner so that the overflow will not interfere with work in the sink. It is a good plan to have a reversible stopper for this type of sink so that a shallow sheet of water is kept in the sink. This aids in preventing excessive splashing when a faucet is inadvertently opened full blast. The extra water also aids in diluting any chemicals dumped into the sink (see figure I.19).

Because of the constant danger of breakage and spillage in chemical work, disposal sinks should be available to each worker close to his usual area of work. It is for this reason that separate tanks apart from disposal sinks and troughs are provided as cooling pans. There is always the danger of contaminating samples by someone using the trough or sink when drawing water or dumping materials, if the sink is required to serve more than one worker at a time.

Troughs running the full length of either wall or free-standing double tables are an advantage, since they provide a disposal convenience at any position. They may be rather narrow, but, being situated some two feet from the front edge of the working surface, may be unsuitable when large quantities of liquids are to be discarded. A large end sink, into which the trough empties, serves this purpose and also allows a high water fixture to be mounted for flushing and filling long or deep equipment. Troughs are quite shallow, and considerable splashing may occur when water faucets are opened. Lead-lined troughs are easily damaged by mercury, and, whenever any considerable amount of the latter is being used, either ceramic-ware or soapstone troughs should be selected.

Cooling tanks or pans are usually quite shallow and may be entirely separate sinks or tanks with water services and waste outlets. Metal cooling pans, approximately one-half the size of the sink, are sometimes provided and are arranged to hang or set in the sink. The best cooling tanks are made of soapstone, ceramic-ware, or with some type of non-metallic lining, especially if cooling coils are incorporated. If a metal tank is used it should be made of a metal similar to that of the coil so that electrolytic corrosion will not occur if acid is spilled in the bath.

Unless the water supplied to the laboratory is unusually cool, refrigeration of cooling pans and tanks may well be considered from the viewpoint of speed and other economies. Individual compressor units may be installed below the cooling-pan areas.

Other types of special sinks to be considered for locations where the conditions warrant special provisions are: mercury sinks, usually of ceramic-ware with provision for trapping mercury and recovering it when spilled; plaster sinks and traps, necessary in hospital and dental laboratories (grease traps are needed in certain processing laboratories); dilution sinks or sumps, often required to meet municipal ordinances.

In locating sinks and troughs, attention should be given to the intended use as well as to the sequence of procedure usually carried on in the work area. As stated before, waste sinks should be immediately available to each worker. Sinks may be located in openings in the working surfaces, between adjacent sections of the tabletops, at the ends of tables, or as free-standing units separate from the tables. When sinks or troughs are installed in openings in tabletops, care must be taken to seal the joint between the sink edge and the working surface.

Island sinks and the working surfaces surrounding them may be made of a material which will withstand the severe conditions imposed and the adjoining surfaces may be of a less expensive material. For example, the sink and top for the island may be of soapstone or one of the heavy duty composition materials, and the adjoining working surface may be treated wood, or some other less expensive material.

HOODS AND OTHER FUME-DISPOSAL UNITS

Fume hoods are usually exposed to extremely corrosive fumes and, normally, must be constructed of materials that are resistant to acids, organic solvents, and alkaline vapors. Fortunately, there are few active alkaline vapors; hence it is infrequent that any part of a fume hood or its ductwork is subject to corrosion from this class of reagents. If the working surface of the hood is reasonably resistant to alkaline action, little trouble will arise, with the possible exception of the fact that in some organic work evaporation of organic ammonia derivatives may occur. However, most of the material normally used in hood construction is quite resistant to alkalies as well as acids. Aluminum is the most common exception. Aluminum is fairly acid resistant but will break down under alkaline action unless covered with a protective coating.

At one time it was common practice to build massive hood structures as part of the building itself. Often the wall of the laboratory room was used as the back of the hood. Chimneys or ductways were constructed back of the hood wall, openings were provided at approximately the level of the working surfaces, and auxiliary openings were provided higher under the point where a sloping-top structure met the wall. The ends and front pilasters were often built of, or covered with, tile. The sloping tops were of stone or tile or they were lined with tile. If sashes were provided, they were usually wood frames and were operated vertically with counterweights. Little or no attempt was made to use baffles and plenum spaces, and, as a result, the hoods either did not purge themselves properly or an excessive amount of air was required to sweep away the fumes.

Many times no mechanical draft was used, dependence being placed on natural draft or chimney action. Natural draft, being dependent on the difference in temperature of the air in the flue and the surrounding atmosphere, gave good results if chimneys were tall enough and the entering gases were hot enough. The temperatures of gases and vapors generated in a hood are often quite low; so if the flues were short, the entire laboratory building was permeated with objectionable odors. This unsatisfactory condition was worse when the number of hoods provided was inadequate. As a result much work that should have been conducted under hoods was done at tables without benefit of hood facilities.

The use of motor-driven fans to produce air movement through ducts and hoods, is the only way to assure fume disposal. In certain installations at places where excessively corrosive fumes are being handled, an induction type of exhaust may be advisable. This induced draft is usually produced by a high-velocity airstream because the use of steam or water involves secondary problems and becomes excessively cumbersome. This so-called venturi draft will not work against a static pressure of more than possibly 1½ inches of water.

Several designs of fans have been developed which operate economically and efficiently under the static pressures normally developed in average laboratory hood and duct installations. The exhaust system seldom develops a pressure of more than 1 to 1½ inches of water. It is important, however, that ducts be of proper size, without sharp bends and abrupt changes in size.

When hoods are a part of the laboratory requirements, early and careful consideration must be given to their location and to provisions for running the necessary ductwork. If duct design is bad, static pressure becomes excessive and over-sized or high speed fans are required. High-speed fans and air moving through ducts at high velocities are noisy.

Fume hoods are cleared of fumes by replacing contaminated air with fresh air. The clean air normally comes from the room and is pushed across the front opening of the hood at a rate of speed dependent upon the difference between the atmospheric pressure within the hood and that in the room. If the air enters the front of the hood at high velocity, burner flames are disturbed and considerable turbulence is set up which blows fumes and dust around, often causing contamination. An excessive volume of air taken from the room is also a heavy drain on heating and cooling systems. Provision should be made for easy entrance of air to the laboratory when the hood is being used, otherwise the entire laboratory is under reduced pressure and insufficient air will enter the hoods. Louvers in partitions or doors for air supply are as essential as is the exhaust duct system. But a positive supply system furnishing filtered and tempered air to the laboratory is preferable.

In a properly designed hood a linear movement of 60 feet/minute is sufficient to move the fumes toward the back of the superstructure. If the proper baffle and plenum arrangements are provided, the fumes will then be entrained in a fast moving airstream and carried into the duct system. The velocity in the plenum spaces may be increased to ten times the rate across the face of the hood, and the fumes in this fast moving stream do not re-enter the working area.

The following minimum standards for movement of air into hoods with a full front opening are recommended as giving satisfactory results:

50 to 60 linear feet/minute for high schools.
60 to 80 linear feet/minute for colleges and hospitals.
80 to 100 linear feet/minute for industrial buildings.

Ducts of circular cross section are most efficient and those of square section next. The efficiency of ducts of rectangular cross section decreases rapidly as the ratio of the two dimensions increases. Elbows should have an inside radius of not less than the smallest cross-sectional dimension of the duct. Branch ducts should be of proper size and should be connected with well-designed "Y" branches.

Air velocities of over 1,500 feet/minute in the ducts are not recommended but systems with velocities up to 2,000 linear feet/minute have worked satisfactorily. Higher velocities may cause excessive noise. Where quietness is essential it will be advisable to keep air velocities down to about 1,000 feet per minute.

Asbestos composition board is an excellent material for hood construction; comparative lightness combined with strength are strong points in its favor. Its resistance to fumes is good and may be materially increased by various types of treatments and coatings. Soapstone, often used for hoods, is extremely satisfactory from the standpoint of resistance, but is heavy, so if it is used careful provision should be made for suitable base cabinets. Proper baffling is also a problem with heavy materials such as soapstone and tile or glass hood linings.

Hoods constructed of asbestos composition board can generally be completely fabricated and shipped assembled, thus saving considerable expense for assembling or relocation.

Stainless steel is adaptable for use with certain chemicals, and the comments that were made in connection with its use for sinks and tanks also apply to its employment for hood construction.

If only organic solvents are to be used, a hood constructed of sheet steel may serve satisfactorily, but in most laboratory work there is little assurance that corrosive fumes will not at sometime be generated.

Hoods may be classified according to their uses. Chemical hoods, for general laboratory work, where anything of a volatile nature may be present, must be constructed of the best corrosion-resistant materials available. Provisions should be made for careful cleaning at frequent intervals and removable baffles are therefore desirable.

Kjeldahl digestion and distillation hoods are standard designs to house units using gas or electric heat. The hood fan may serve to exhaust the units, but the most satisfactory arrangement is to have a separate exhaust fan and duct. The fan and stack are usually high-silicon iron, but stoneware and lead are also suitable materials for the stack (see figure I.19).

Hydrogen sulfide hoods are modified only to the extent that the stopcocks are usually hard rubber. The cupboard base, if properly vented through the superstructure, may be used to store a gas cylinder, thus providing satisfactory control of the odor.

Water- and steam-bath hoods must handle an excessive amount of moisture, which is difficult to accomplish without exhausting large volumes of air from the room. Provision should be made to allow condensation to drain from the exhaust duct system.

Perchloric acid hoods require special design and careful attention. Perchloric acid reactions generate perchlorates that are easily detonated in the presence of organic matter. Collections of the residue must be carefully removed and contact avoided with organic materials in the hood, duct, and fan. Materials used in the construction of the hood and exhaust system should be inert, non-absorbent, and free of any organic impregnation. All joints should be made liquid- and gas-tight with an inert cement. Water spray pipes may be installed for washing down the back surfaces of the baffles in the hood and provision should be made for carrying away this flushing water. In some hoods baffles are removable for easy cleaning of the entire interior of the hood. If hot plates are installed in such a hood, it is advisable to provide removable liners or shields of asbestos, composition, or tempered glass across the end and back of the hood structure where the hot fumes strike. This procedure protects the hood structure itself, and new liners are easily and inexpensively installed.

It is recommended that separate fan and duct systems be installed for perchloric acid hoods and that these be arranged for easy, thorough, and frequent cleaning. The vent duct should be made of a corrosion-resisting welded metal arranged preferably as a vertical stack. Draft may be supplied directly by a cast-iron fan with bottom horizontal discharge for easy cleaning, or it may be induced. Access panels should be provided so that steam or air may be used to loosen and drive out collections of material that may contain perchlorates. Vent systems are sometimes cleaned by water-spray nozzles installed at the top of the duct and at bends.

Etching hoods impose the problem of handling excessive condensation, and the hoods need to be cleaned regularly. Provision should be made for condensation gutters in the hood and for draining the duct. Access panels for cleaning concealed areas are advisable. If horizontal runs are necessary the duct should be properly sloped and drain connections provided at the low point. It is a good idea to provide a separate exhaust fan for the etching hood or hoods to insure control of fan operation until the acid bath has cooled sufficiently to stop fuming.

Organic-solvents hoods intended to handle gums, varnish, and other solvents may be of metal and may be lined with heavy paper or coated with paint capable of being stripped for removal of deposits. Care must be taken to keep flames and heat away from such hoods, and it is preferable that they be placed on the outside of the building, or in a separate fireproof room provided with an automatic carbon dioxide or water sprinkler.

Since virus hoods present contamination problems, the exhaust should be forced through a hot gas or electric grid before being allowed to enter the atmosphere. Radio isotope hoods are described in another section.

Hood ventilation has been discussed in the introduction to this chapter. Open-front hoods or hoods without front sash are the most convenient, and, with proper design and adequate drafts or ventilation, sash is not necessary. Sash is valuable in case of sudden generation of excessive fumes or to smother flames. By partially closing the sash, the velocity of the purging air is increased across the smaller opening; by closing the sash entirely flames may be smothered. Such sash should be glazed with wire glass, laminated safety glass or annealed glass to avoid danger from broken glazing.

Canopy hoods with sidewalls are recommended over sinks used for fuming liquid disposal, and over steam tables, wash sinks and acid baths other than deep etching tanks. Such a canopy hood should be installed as low as possible and adequate draft should be provided. Canopy hoods are often open on all sides, and there is opportunity for cross-drafts to carry the fumes outside the area of the canopy. The canopy should be larger in area than the working surface below it, and at least 500 cubic feet/minute should be provided per foot of length of the longest side. For example, a 6-foot long canopy should exhaust 3,000 cubic feet/minute (see figure I.19).

Small table hoods of various designs are available from laboratory equipment manufacturers. These hoods are adaptable to student use or to industrial use for routine work when the requirements are not severe. Many of these hoods are designed for down-draft exhaust. This usually means that a complicated exhaust-duct system is involved and that the static resistance of the system is usually high. Also, the duct system is often of small cross-sectional area which requires that the air must flow at high velocity in the duct. Several of these small hoods are usually located in the laboratory fairly close to each other. A 12-foot student table may have four double student hoods located as close as 2 feet apart. The room air thus has several exit points; and the draft on the hoods should therefore be positive and all work kept well within the area of its hood. One advantage of such hoods is that they quite adequately ventilate the room since stray fumes quickly find their way into the area of some hood. The hoods are usually low to avoid obstructing the view in the laboratory, and the capacity for temporarily holding large volumes of fumes is consequently small. Provision should be made in such a laboratory for some standard hood installations so that unusual or high setups can be accommodated.

Care should be taken to supply air to the laboratory when a number of hoods are in use. A laboratory with six student tables each having hoods to accommodate eight students will require approximately 2,400 cubic feet/minute for the student hoods alone, and, with adequate wall hoods, this requirement can easily mount to a total of 4,800 cubic feet/minute. This means a complete change of air in the laboratory every 3 minutes, or 20 changes per hour. This is not excessive, but provision must be made for the admission of this quantity of air to the laboratory, either from the corridors or from some outside source.

High hoods with sidewalls and backplate or walk-in type hoods are often required in industrial research and engineering teaching laboratories. The volume of air required properly to ventilate this type of hood is approximately double that of a standard hood, because the area of the opening is twice that of an ordinary hood. If the fumes are to be properly directed, the face velocity of approximately 60 linear feet/minute must be maintained and provisions be made for exhausting through slots in the rear wall and at the top. Sash on walk-in type hoods enable the purging of the hoods to be accomplished with less air since by partially lowering the sash, the face velocity will be increased. Normally the volume of fume generation in this type of hood is not excessive.

Ordinarily, fume hoods are connected to an exhaust system only. With this arrangement, as stated before, all the purging air must enter the hood through the front opening, and this air is taken from the laboratory. If the number of hoods in the laboratory is not excessive in proportion to the size of the room, this arrangement is usually satisfactory. The hoods serve the double purpose of disposing of fumes that are harmful and of removing vitiated or objectionable room air. Many fumes not particularly dangerous are likely to be present in an active laboratory, and the operating hoods change the room air frequently enough to provide good ventilation.

When the number of hoods located in a laboratory is large in proportion to total cubic content, these hoods can often remove the air so rapidly that it becomes difficult and expensive to maintain proper temperature conditions. This is particularly true in air-conditioned laboratories, where the air is not only tempered but also filtered and held at proper humidity.

In order to conserve the laboratory-conditioned air and to hold the number of air changes in the laboratory to that required by the conditioning system, the fume hoods themselves require an auxiliary air supply. This air supply does not need to be conditioned air in the sense that the room atmosphere is conditioned, but it may be filtered and possibly tempered in cold weather. The tempering is done in order to prevent condensation on the outside of the supply ducts and not because the raw air has any particular effect on the operation of the hoods. The type of hood in which both exhaust and supply air systems are involved is variously designated as "air-conditioned hood", "self-ventilated hood", or "pressurized hood". Such hoods may also be referred to as "induction-type ventilated hoods", or "self-purging hoods" (see page 61).

The manufacturers of laboratory equipment have developed hoods of various designs that utilize mechanically supplied air to replace a part of the air that normally enters the hood from the room. The amount of room air so conserved depends on the balance set up between supply and exhaust systems, the design of the hoods, and the requirements of the laboratory. The amount of room air conserved ranges as high as 70%. In theory the total room-air requirement could be conserved; but because the hoods are often operated with the sash raised, a certain velocity of air into the hood through the front is required in order to direct generated fumes away from the front and into the hood itself. Because of this condition, when a number of hoods are involved in an installation, the hood requirements must be carefully considered and the air changes required by the hoods made a part of the air-conditioning plans.

Normally a better method is to allow the hoods to take enough air from the room to hold the air changes to the required number. In other words, the hoods are operated as a part of the air-conditioning system. Only when the hoods are required to handle fumes is any auxiliary supply air forced into them. When the supply air is turned into the hoods, the exhaust capacity is increased in the same volume. This keeps a constant flow of a definite volume moving into the hoods at all times and conserves the conditioned room air.

Another advantage of the self-ventilating hood is that it will purge itself even with the sash completely closed, since a continuous supply of purging air is mechanically supplied. The exhaust and supply fans should be interlocked to insure that the exhaust fan will always be operating at maximum speed before the supply fan is put in operation; otherwise contaminated air will be forced into the laboratory. This provides an extra margin of safety in critical work such as investigations of virus diseases and radioactive work.

STORAGE AND DISPLAY CASES

Storage cases are of two general types—full height cases and top and base section cases. A full height case has a single compartment with or without doors; it is usually 7' high by 16" or 22" deep and may vary in width from 3' to 6'. The more common widths are 3', 4', and 6'.

A top-and-base-section case, as the name indicates, is a storage unit made of a base section and a top section. The base section is a cupboard or drawer unit of the same design as the base cabinets used in worktables. The top section is a unit of cupboard design with open front or with sliding or hinged doors. The top sections are approximately 4 feet in height, so that the over-all height of these two sectional units is the same as a full height case. The upper sections, usually 16 inches deep, are equipped with two, three, or more adjustable shelves. When such a top section is placed on a standard base unit, a convenient ledge is formed in front of the upper section. By using standard cases it is possible to assemble many arrangements of cupboard, drawer and full height cases without the use of special or custom-built units (see figure I.15).

In addition to the above arrangements, top section cases may also be mounted on the wall 12 to 18 inches above worktables or case base sections. These "wall-hung" cases are available in 30- and 48-inch heights from most manufacturers. A battery of cases can thus be assembled to give the required facilities and still keep the assembly orderly and well designed. Cases higher than 7 feet may be obtained by placing an additional top section above.

BATHS, PLATES AND PANS

Baths, plates and pans, for either heating or cooling, are important parts of laboratory equipment. Except in student tables these units are used repeatedly and are most satisfactory when built-in as a part of the equipment. Waste crocks may be more versatile than waste sinks, but the sink with its waste outlet and water supply is much more serviceable. A portable gas plate may be advisable in certain routine work when used intermittently. For frequent use a built-in hot plate, flush with the working surface of the hood, is most convenient. Beakers may be placed on it and removed from it easily without excessive lifting, and the hot-plate surface, being level with the adjacent working surface, may be utilized for work when the plate is not hot. The controls for the plate are usually mounted on the apron rail of the base cabinet and are not subject to corrosion caused by splatter and spillage. Recessed or built-in hot plates, either gas or electric, are offered in various sizes and are housed in the equipment unit in such a manner that any spillage is taken care of by a drip pan. The result is that the working surface of the hood is free of obstruction and easily kept clean. The same advantages are derived from recessed water and steam baths, cooling pans and plates.

Baths, hot plates, and pans should be located inside hoods. Cooling pans may be placed adjacent to hoods, if the beakers, when placed in the cooling bath, are not giving off objectionable fumes. It is often convenient to remove a beaker from the hot plate, allow it to cool sufficiently to stop fuming and then place it in a nearby cooling pan for further temperature control (see figure I.7).

A sink within a fume hood is always advantageous since it enables disposing of fuming waste and cleaning of apparatus, and also provides a place to care for fumes if breakage or spillage occurs.

Drain pans built flush in the tabletop adjacent to a sink are convenient and take the place of drainboards and possibly of pegboards. These shallow pans are connected to a drain and are equipped with a plated or stainless-metal insert which is expanded or punched. Such arrangements aid materially in good housekeeping procedures.

Acid baths are best located in hoods. This action is imperative if the bath is to be heated. Careful consideration should be given to methods of heating the bath. Use of immersion heaters and steam jackets is objectionable because of the necessity of fixing or permanently installing the bath. A fixed acid bath requires a waste connection, and the method of stopping the waste outlet may be a difficult problem. The practice of placing a portable acid bath either on an electric or gas hot plate often solves the problem most simply and satisfactorily. The hot plates may be set below the working surface so that the top edge of the bath will be level with the working surface. A sink adjacent to the acid bath makes disposal of the bath contents easy, and the entire bath may be removed and thoroughly cleaned at intervals.

Individual steam baths or cones are convenient additions to hood equipment, especially in organic work. These individual units are extremely useful additions to students' tables in organic chemistry laboratories.

It is advisable to give careful consideration to the accessories which may be needed and to incorporate the requirements as part of the equipment when it is being designed. Otherwise, extra apparatus will have to be supplied later, and oftentimes space to accommodate it is unavailable. The final result may be a cluttered and crowded working area.

SERVICE FIXTURES, LINES, WASTE LINES AND TRAPS

Laboratory service fixtures, in common with other laboratory equipment, are subject to severe corrosion. This is especially true of fixtures mounted in fume hoods. In addition, fixtures on teaching-laboratory equipment are subject to excessive mechanical wear. To meet this requirement, heavy-duty fixtures have been designed and are available from laboratory equipment manufacturers. Such fixtures are made of the most corrosion-resistant materials available within reasonable cost limits. The use of bronze and brass for the bodies of fixtures is almost universal. Such materials as stainless steel and white metal have been considered at times, but the cost and manufacturing problems involved make their use impractical.

Water, gas, air and vacuum fixtures are entirely serviceable without any special treatment of the inside of the fixture. For the protection of the outside several methods are used in addition to the usual process of plating with nickel or chrome. These include coating with rubber, a silicone or with chemically resistant inert resins that are sprayed on a fine sand-blasted surface. The spray coatings are near the same level of cost as nickel and chrome plating. The advantage of the resin coatings is that they do not tarnish nor peel as easily as do nickel and chrome and they can be renovated without removing the fixture from its mounting.

The best of laboratory fixtures have to be replaced at intervals and should be designed so that this may be done without difficulty. Specialized heavy-duty fixtures are therefore likely to be more economical and convenient than ordinary plumbing fixtures, although the first cost may be somewhat higher.

For servicing certain fluids and gases, such as distilled water, brine, acids, and hydrogen sulfide, special equipment is required. Distilled-water faucets are usually lined with tin or silver. Brine and acids may require ceramic cocks; hydrogen sulfide usually requires hard-rubber or aluminum cocks and lines.

Fixtures are designed for mounting on a horizontal surface such as a tabletop or on a vertical surface such as an apron rail or tunnel face. They may also be installed on horizontal pipe lines beneath a reagent or bottle shelf. With this type of arrangement the water line is usually the lowest and the cocks point downward into a trough or into cup sinks (see figure I.19).

Tabletop mounting usually brings the fixtures at the most convenient location, but imposes the problem of cleaning around the fixture bases. The newer designs of fixtures have reduced this objection.

Fixtures mounted on vertical surfaces leave the tabletop clear, but mounting them on apron rails imposes the problem of having hose and cable connections hanging over the edge of the working surface. If there is sufficient overhang, holes may be bored along the edge of the top so that the connections may pass through them. The mounting of fixtures on the apron rail on hood base sections is recommended for it keeps them out of the hood superstructure and away from fumes. The fixtures are often mounted on a recessed panel just below the narrow front rail of the base section to protect them from spillage and to keep them from catching on clothing (see figure I.7).

Mounting fixtures on the vertical face of a plumbing tunnel is an excellent arrangement where no trough is required. The top of the tunnel may serve as a reagent shelf. Water connections may be mounted over or adjacent to small cup sinks. Cup sinks are available for both vertical and horizontal mounting (see figure I.16).

Mounting fixtures in parallel horizontal lines below reagent racks usually places them at convenient positions. This arrangement also simplifies the installation since double fixtures can be supplied at a 90° or 180° angle by using a side outlet tee or cross in the line.

Island and turret mountings provide for the close grouping of services in limited space. Islands usually provide for housing sinks; they likewise afford a mounting for water and other services.

Tray plugs, stoppers, traps, and drain lines are subject to very severe corrosion. This is particularly true of traps. Active reagents may stand in the trap for some time before being properly flushed. Drain lines are not subject to such severe service because, when properly installed with sufficient slope, the waste will drain away promptly.

The usual materials for sink fittings, traps and drain lines include high-silicon iron, chemical stoneware, cast iron and lead. For ordinary service lead is excellent and is also most easily fabricated and installed. However, it amalgamates with mercury and special precautions should be taken if mercury is likely to get into the drain. Traps equipped with properly designed removable plugs will catch and hold spilled mercury. The clean-out plugs are easily and inexpensively replaced. Materials, such as TNT, which are subject to detonation, should not be trapped.

Municipal codes vary widely in the regulations relative to venting, reventing (loop venting), using lead for acid waste, and placing of sumps or dilution sinks. Seldom does the code definitely exclude the use of lead for acid waste. Codes need to be checked carefully as to the requirement for the incorporation of vacuum breakers on water-fixture lines.

The laboratory equipment industry has carefully designed equipment properly to accommodate waste lines and traps. Because of this and the frequent necessity of connecting several sinks or other waste lines to one drain, it is usually best to include the traps and waste lines as a part of the equipment. By following this procedure, adequate access panels and drain line supports will be included in the equipment just as sink supports are provided when sinks are included.

ARRANGEMENT OF LABORATORY EQUIPMENT

The equipment in a laboratory, particularly an industrial laboratory, may be arranged in many different ways. The arrangement in teaching laboratories is, in general, more standardized since courses of study and laboratory periods are similar in most schools. Furthermore, the optimum space per student has been quite well fixed so that the size of a laboratory for a given number of students is readily determined. The types of work done in industrial laboratories vary so greatly that it is difficult to set up any standards, and furthermore provision must be made for expansion (see figures I.7 and I.8).

Techniques that are standard today may be outmoded tomorrow. Industrial planning is usually done with the profit motive in mind. An industrial laboratory can become obsolete very quickly, and then it is a liability. Teaching laboratories are not nearly so vulnerable in this respect. Well-engineered furniture units, properly planned in arrangement, lend themselves to relocation without excessive waste. As far as possible, the work to be done should be carefully determined and the laboratory equipment should be selected and organized to provide for the highest efficiency possible.

Often a laboratory is designed not only as a workroom but also as a sales asset, in which case attention must be given to layout from the standpoint of appearance as well as from that of working conditions. If the laboratory is to be partially for sales promotion purposes, open spacing and glass partitions should be considered. Aisles for viewing the laboratories without actually entering the work areas are advisable. Provisions must be made for demonstrations without interference with the technician's work. This problem is not too serious when frequent visits are made, since the personnel soon become accustomed to it and work proceeds without undue interruption.

The responsibility for knowing what a laboratory is intended to accomplish lies with its director and not with the equipment engineer representing the furniture manufacturer. However, close cooperation between the two usually results in a satisfactory installation. When an entirely new laboratory is being developed it is a good plan for the owner to have the benefit of a specialist who will take the time to study the requirements in detail. The experience of the service engineer of the equipment manufacturer is helpful because he can adapt to the specific problem arrangements with which he is familiar.

Work habits and methods used in analysis largely determine laboratory arrangements. For example: a sulfur hood fitted with a bank of Argand burners might be requested, or this equipment may be considered obsolete and other sulfur setups required. Balance work and titration stations may be decentralized and located in various work areas or they may require separate rooms. Hoods may be arranged in banks or planned so that each work area has a hood adjacent to it. Individual laboratory rooms, or one large room, with or without low partitions, are other alternatives.

The metallographic laboratory is a good example of the possibility of careful planning adding much to the efficiency of the final arrangement. A suite comprising a sample preparation room, spectrograph room, darkroom, densitometer and calculating table room, record and office room may well be considered for this laboratory. The sample preparation room can comprise both physical and chemical preparations. A physical bench with a heavy wood top is needed for mounting a vise and drill press for obtaining samples of proper size. If salts and organic compounds are to be analyzed, a certain amount of chemical preparation is necessary in order to obtain an impregnated or crater-filled carbon electrode. Thus a chemical worktable with a fume hood, sink, and all the standard service outlets is essential. The hood may be equipped with a hot plate, sink and services and may also provide space for an oven.

The arrangement of the spectrograph room depends on the type of instrument to be used. With one type of spectrograph, an L-shaped table is needed, while with another no table at all is required, but the film-loading section of the instrument is located in the darkroom. Space must be provided in the spectrograph room for accommodating the various cabinet units which control the electric current. A fume canopy may be required over the sparking unit of the instrument.

The darkroom is intended to handle the film strips only and so may be a fairly standardized layout. A maze for entering and leaving the darkroom is the most convenient arrangement. This room should be properly ventilated and preferably is air-conditioned. The worktable should have facilities, not only for developing, fixing, and washing the film but also for storage of chemicals and preparation of the photographic solutions. A film-drying unit may be a part of the darkroom equipment. A pass box between the darkroom and the spectrographic room adds to efficiency when the volume of work is heavy.

The densitometer and calculating units can be housed together, but the densitometer should be located so that it is shielded from the sparking units of the spectrograph. Usually special tables are required for both the densitometer and calculating board. The office and record room requires an office desk and a special file case to keep films properly stored and classified. For certain types of work, air-conditioning may be necessary for the entire suite with the possible exception of sample preparation and office section.

4

PLUMBING

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In addition to the normal building services, a modern laboratory must have an adequate source of supply and system of piping for some or each of the following services:

A. Steam at high and low pressures
B. Condensate
C. City water
D. Well water or nonpotable water for cooling or similar services
E. Hot water with provision for circulation if the system is extensive
F. Distilled or deionized water
G. Compressed air at high and low pressures
H. Vacuum — normal, special and high
I. Gas — natural, manufactured or bottled
J. Hydrogen
K. Oxygen
L. Nitrogen
M. Hydrogen sulfide
N. Waste lines
O. Refrigeration

Laboratories may consist of one or a number of rooms on one floor of a manufacturing building, many rooms on several floors of a large building designed and constructed solely for that purpose, or intermediate arrangements between these extremes.

The service piping is an important part of the laboratory and unless given proper consideration in the preliminary stages of the design may not only spoil the appearance of the building but also prove a constant source of trouble and expense. If properly designed and installed, however, even exposed service piping need not detract from the appearance of a laboratory and will provide long-time trouble-free service.

When building or equipping a laboratory it is always advisable to use the services of competent engineers familiar with the problems involved, as well as the equipment and materials available for the best solution of these problems.

Before considering the general distribution system, it will be advantageous to review the individual services and their source of origin for the laboratory.

STEAM

Steam is usually brought to the building at a higher pressure than necessary for normal requirements. For ordinary laboratory services, building heating and generation of hot water, steam pressures up to 15 psi are adequate. Steam for heating water for general purposes and for washing laboratory glassware and other apparatus should be taken off the laboratory low-pressure system rather than the heating system, because hot water for these services will be required whenever the laboratory is in use.

Stills may require pressures up to 30 psi while hot plates, etc., may require steam at the maximum pressure available in order to obtain the necessary temperatures at their surfaces. In some cases a small amount of steam at higher pressures than is available from the source of supply may be required. In such cases a motor-driven compressor may be used to compress the steam to this higher pressure, thus eliminating the necessity for the installation of a small high-pressure boiler.

Separate pressure-reducing valves should be provided for high-pressure steam to laboratory equipment and low-pressure steam to the general laboratory services and to the heating system.

Shut-off valves should be provided on each side of a pressure-reducing valve and a by-pass with a globe valve should be installed for use if the pressure-reducing valve is out of order. A strainer should be installed ahead of the pressure-reducing valve, and a relief valve and a pressure gauge on the low-pressure side of the valve. The pressure gauge provides a means for checking the operation of the pressure-reducing valve, while the safety valve protects the system against excessive pressure in case of failure of the pressure-reducing valve. A recording steam-flow meter may be provided to determine the quantity of steam used.

Steam lines should be standard-weight black steel pipe. If no changes in the system are expected, welding may be advantageous but where frequent changes are probable screwed or flanged cast iron fittings should be employed. Globe valves should be used for lines under 1¼ inches and gate valves for larger lines.

CONDENSATE

The bottoms of risers, ends of all mains and long branch connections should be dripped. All air and condensate should be removed through bucket traps or combined-float-and-thermostatic traps. Provision should be made for the rapid removal of condensate and air from all heating surfaces. The condensate is normally collected in a receiver which is vented to the outdoors, and pumped to the boiler room. The air and vapor rise to the top of the receiver and are released through the vent pipe. However, when the condensate pump empties the receiver it causes a reverse flow of air from outdoors which may introduce sufficient oxygen or sulfur dioxide (if vent is located near a smoke stack) to cause the condensate to become corrosive.

A vacuum system will provide a positive discharge of air and gases to the outdoors but special precautions may be necessary to prevent leakage of air into the system around valve stems and elsewhere.

Condensate lines should be of genuine wrought iron or extra-heavy steel with fittings, joints and valves as specified for steam lines or they may be of copper tubing with sweated joints.

CITY WATER AND WELL WATER

A source of pure, uncontaminated water should be available for all sanitary and laboratory equipment used for supplying water for drinking purposes, for bathing or washing of cuts, burns, etc., or for the preparation of food products or medical supplies.

Water for cooling or other industrial uses may be reused water or it may be obtained from sources which are not satisfactory for the purposes listed above. However, there must be no cross connections between the two systems.

Usually water is brought through underground mains to a suitable location in the laboratory building where a valve and meter may be installed. Water lines should be pitched back sufficiently so that they may be drained near the point of entrance in case it is necessary to shut off the water in cold weather or to make changes or repairs.

City and well water lines should be standard-weight steel or genuine wrought iron, galvanized, with cast iron fittings (galvanized in the smaller sizes) or copper pipe with sweated fittings. The same kind of valves are used as for steam lines.

HOT WATER AND HOT WATER CIRCULATION

Hot water may be obtained from a storage-type water heater with either an internal or external heating element or from an instantaneous-type steam heater. The instantaneous heater will probably cost less than the storage heater and will occupy less space yet it will continuously supply hot water up to the limit of its capacity. However, such a heater does not permit as close temperature control as a storage-type heater.

Storage-type water heaters should be made of copper, copper-bearing steel or other corrosion-resistant materials. They should be equipped with removable heating units and supplied with low-pressure steam (for best temperature regulation) controlled by thermostatically-operated steam valves. The thermostatic elements should be inserted in the tanks about two-thirds of the distance from the bottom. Hot-water tanks should be equipped with relief valves to prevent development of excessive pressures as the water is heated.

If steam is not available, gas or electric water heaters may be used.

Wherever possible, the ends of a main or long branch should be connected to a fixture which is used frequently; thus a reasonably continuous flow of hot water will be available in the mains, and the only cold water wasted will be that in the short branch connections to fixtures which are not used frequently.

For extensive distribution, either a gravity system or a forced circulation system may be used. In tall buildings a gravity system is satisfactory. With low buildings and long mains, however, gravity circulation is not always satisfactory, so a small circulating pump should be provided on the return side of the system near the heater. Sufficient hot water should be circulated to offset the heat loss through the combined supply and circulation mains and to allow a drop of only about 5° to 10° in the temperature of the water.

Wherever possible, an upfeed connection should be provided from the main to at least one fixture, in order to vent air from the system.

Copper with sweated fittings is preferred for hot water lines and valves should be the same as for steam lines.

DEIONIZED AND DISTILLED WATER

In many laboratories water free from minerals such as sodium, potassium, calcium and magnesium sulfates, carbonates, bicarbonates, etc., is satisfactory and may be obtained with deionizing or demineralizing equipment at much lower cost than by distillation. The equipment used for this purpose causes the water to be treated to flow through two alternately arranged beds, one of synthetic cation resin and the other of anion resin. The cation resin attaches the dissolved metallic ions to itself and replaces them with hydrogen ions. Thus the dissolved salts are converted to their corresponding acids. The anion resin then absorbs these acids and delivers a mineral-free water. When the exchange capacity of the resins is exhausted they are regenerated without the use of heat by means of a low-cost regenerant solution. Equipment for this service, in various capacities, is available from several manufacturers.

In many laboratories it is necessary that the water, in addition to being free from the minerals noted above, also be free from organic, inorganic, gaseous, bacterial and pyrogenic impurities. For this service a still may be furnished in which the water is first preheated and vented to remove the gases, and then converted to pure dry steam by gently boiling with vapors disengaging at low velocities in a suitably proportioned and baffled evaporator, and finally condensed in a tin-lined vented condenser. Wherever extra purity is required for laboratories in hospitals and pharmaceutical manufacturing plants, double or triple stills may be used.

Extremely pure distilled water may be required in research laboratories for conductivity and solubility determinations. Stills for producing water with a conductivity of approximately 0.7×10^{-7} reciprocal ohms at 25°C have been installed in some of the leading universities. Stills of this type are designed for batch operation and are not recommended for use in hospitals or ordinary laboratories.

If the deionized or distilled water is to be piped to several locations, materials must be used that have no effect on the water. Block tin, aluminum and glass satisfy this requirement, but consideration must be given to the method of making joints between adjacent sections of pipe. When threaded joints are specified, the use by the plumber (specifications to the contrary notwithstanding) of joint compound on the pipe threads may cause contamination of the water in the system. Soldered joints in block-tin pipe present the possibility of use of soldering materials which may provide a source of contamination. Flanged joints for aluminum and glass pipe, unless made with gaskets of chemically inert material, also offer a source of contamination. Gaskets made of "Teflon" (polymerized tetrafluorethylene) are chemically inert from extremely low temperatures up to 572°F and should provide a means for making a tight joint for either flanged aluminum or glass pipe systems which will not affect the purity of the water.

A distilled water piping system, after assembly should be flushed out with city water, then filled with distilled water and allowed to stand for 12 hours. The distilled water should then be drained and the system refilled with fresh distilled water. After 12 hours, the system should again be drained and then is ready for use.

COMPRESSED AIR

Compressed air for laboratories is commonly supplied at 5 to 10 pounds pressure except where air mixers are used extensively, in which case air should be supplied at 20 pounds pressure. Even higher pressures may be required for special purposes. At 5 pounds pressure the ordinary laboratory cock will discharge 1½ cubic feet of air/minute and at 10 pounds, approximately 3 cubic feet/minute.

To supply compressed air a motor-driven rotary air pump or reciprocating compressor may be installed in a service-equipment room. Non-lubricated types of reciprocating air compressors can be furnished if required to supply compressed air free from any trace of oil. If both low- and high-pressure air are to be supplied to the laboratory, separate compressors should be used. Air compressors may be air-cooled or water-cooled, the latter being preferable, especially for air at high pressures.

Determination of the size of the compressor is a matter of judgment rather than calculation on the part of the engineer since the demand will vary constantly. For a limited number of cocks, a compressor may be provided that is capable of supplying the full demand with all cocks in use. A compressor should always have a receiver so that the compressor will not run constantly and thus have a longer life and require less maintenance.

The air intake should, if possible, be taken from outside at a location where clean, cool air is available. It should be turned down and protected by a wire screen so that large particles of dirt or rain cannot be drawn in. A filter should be provided to protect the compressor against excessive wear due to dust particles in the air; in addition, a silencer should be installed if the air intake is in a location where noise may be objectionable.

There should be no valves between the compressor discharge and the receiver. The receiver itself should be provided with a pressure gauge, a relief valve, and a drain cock near the bottom to drain off any moisture.

Where dry air is essential, high pressure units should be equipped with a water-cooled after-cooler to reduce the temperature of the air leaving the compressor to condense out excess moisture.

To maintain uniform pressures in the system, the compressor may deliver air to the receiver at a pressure higher than that required, and a pressure regulator installed to supply air at a constant pressure. A pressure switch at the receiver will provide control for the operation of the compressor.

Pipe, fittings and valves should be the same as those specified for steam lines. The use of white lead or other suitable joint compound to insure tight joints, is desirable when making up screwed connections.

VACUUM

For normal laboratory requirements, vacuums (at outlets) from about 14 to 20 inches of mercury are adequate. Vacuums in excess of this are likely to ruin filter papers. For laboratories where it may be necessary to exhaust air from such items as lamp tubes, vacuums up to 28 inches or more may be required.

For vacuums of from 14 to 20 inches a good grade of rotary vacuum pump may be installed. Because the volume of air to be exhausted per cock may vary from 1 to 3 cubic feet/minute and the percentage of cocks in use at any one time is unpredictable, the determination of the proper size of vacuum pump to be furnished is a matter of good judgment rather than mathematical computation.

If the vacuum pump is to be operated automatically to maintain a vacuum on the system, it is essential that it should not be appreciably oversized. A pump that is larger than needed may cause cycling unless either a large vacuum chamber, a vacuum breaker or a bleeder connection is provided. Vacuum chambers of a capacity effective to prevent too frequent stopping and starting of the pump, may become quite large. Vacuum breakers which open suddenly at a predetermined vacuum may cause objectionable fluctuations in the systems and a bleeder connection which is continuously in use is extravagant in the use of power.

For maintaining the higher vacuums required in special laboratories, a high-grade reciprocating vacuum pump may be installed; and since this demand will probably be uniform, the pump can be sized accordingly and run continuously.

For the maintenance of pressures from 1.0 to 0.1 microns a rotary high-vacuum pump may be used. These pumps may be obtained to operate at capacities of from 0.8 to 10 liters/second at one micron, and to maintain guaranteed vacuums from 0.3 to 0.1 microns.

Piping between vacuum pumps, or outlets on laboratory benches and equipment, should be of black steel with fittings and valves as described for steam lines. Where screwed connections are to be used it is important that the threads on pipe and in fittings should be accurately cut and clean. After the line has been carefully made up, dissolved beeswax or varnish should be applied to the threaded joints while the system is under a vacuum in order to seal off any small leaks. It may be necessary to make two or three applications before all leaks are stopped.

Traps should be provided at convenient locations in the system ahead of the vacuum pumps. These will prevent scale and water or other liquids which may be pulled over in filtering equipment from getting into the pump. For ordinary laboratory services a standard vapor-proof lighting fixture will provide a good trap as it is tight and any accumulation of liquid or dirt can be readily seen and removed.

For use with diffusion pumps or high-vacuum pumps for maintaining pressures measured in microns, it is desirable that the piping between the pump and the equipment from which the air is to be exhausted should be as short as possible; it must, of course, be perfectly tight. Glass tubing is frequently used for this purpose.

GAS

Gas supplied to laboratories may be manufactured gas which normally has a calorific value of 550 Btu per cubic foot, or natural gas with a calorific value of 1,000 Btu per cubic foot. Gas is usually piped to the building at an average pressure of about 6 inches of water. This will cause a flow through a standard gas cock of about 14.5 cubic feet/hour. At the minimum pressure to insure satisfactory operation of Bunsen burners (3.5 inches of water) the flow is reduced to about 8.5 cubic feet/hour.

Glassblowing equipment may require gas pressures of 6 psi or more. A gas booster must be installed to obtain these pressures. Where pressure requirements are less than 1 psi, centrifugal fan-type boosters are preferable. If a booster is used, means must be provided to insure that the pressure on the suction side is not reduced to the point where flames are extinguished.

If neither manufactured nor natural gas is available, propane or butane gas may be used. Either of these can be supplied in standard-size cylinders which may be installed singly or manifolded together and connected through suitable pressure regulators to the laboratory distribution system.

The pressure in a cylinder of propane at 70°F is 109 psi and the cylinder contains 850 cubic feet of gas at atmospheric pressure. The pressure in a cylinder of butane at 70°F is 19 psi and the cylinder contains 640 cubic feet of gas at atmospheric pressure. Where propane, butane or other gas is supplied to the laboratory from cylinders, regulators must be provided to deliver these gases at pressures and rates of flow which will meet the requirements of the laboratory. Single-stage regulators are not usually accurate below 5 pounds pressure, and two-stage regulators below 2 or 3 pounds. The pancake type of regulator will usually provide accurate control from 3 ounces to 4 pounds.

Regulators should when possible be installed out of doors. If this is not practicable the relief connection should be piped outdoors and above the building roof.

Gas piping for manufactured or natural gas should be standard-weight black steel pipe with malleable or steel screwed fittings or welded joints. White lead in linseed oil should be used as a joint lubricant. Joints for piping systems for use with propane or butane should be welded or brazed. Plug-type cocks are preferable for use as stops in gas lines. For larger sizes these should be the lubricated type.

HYDROGEN, OXYGEN AND NITROGEN

Hydrogen, oxygen and nitrogen can also be supplied in standard-size cylinders which may be installed in a manner similar to cylinders of propane and butane.

Oxygen cylinders and manifolds should be separated from cylinders and manifolds containing flammable gases by 2-inch partitions of cement plaster and metal lath on a steel framework or other structure having equivalent fire- and explosion-resistance characteristics. Cylinders, manifolds, regulators, valves and all connections should be kept free from oil, combustible materials and pipe scale.

All parts of manifolds, regulators and piping for oxygen systems which are exposed to cylinder pressures should be constructed of nonferrous materials designed to withstand very high pressures. Joints of the manifolds may be welded, soldered or screwed. Screwed joints should be made up with litharge and glycerine or with water and glycerine if the pressure is over 300 psi.

The pressure in hydrogen, oxygen and nitrogen cylinders at 70°F is 2,000 psi and the cylinders contain approximately 200 cubic feet of gas at atmospheric pressure.

All parts of manifolds and piping for hydrogen and nitrogen systems exposed to cylinder pressures should be constructed of extra-heavy steel pipe with forged steel fittings. Joints should preferably be welded, but, if screwed, they should be made up with litharge and glycerine.

Regulators should be a two-stage automatic type of sufficient capacity to permit the desired rate of flow, designed for use with free gases, and equipped with a relief valve on the low pressure side so that excessive pressures cannot build up in the distribution system.

Piping on the low-pressure side of hydrogen, oxygen and nitrogen supply systems should be standard-weight black-steel pipe with malleable screwed or welded steel fittings.

Where threaded pipe joints are required, sharp dies should be used to insure perfect threads; the threads in fittings should be carefully examined to insure gas tightness. Joints should be made up with a relatively dry mixture of litharge and glycerine and care should be taken to keep any of the compound from entering the pipe. Before the pipe is installed, all fittings and pipe should be hammered to dislodge dirt and scale which should be blown out by compressed air or steam.

Valves for oxygen lines should be metal-to-metal seated globe valves of the packed stem or packless diaphragm type. Before being installed valves should be dismantled and thoroughly cleaned with a nonflammable solution as described later for cleaning the piping. Valve packings, if oily, should be removed and replaced with a suitable substitute such as dry asbestos wicking.

If lubricated cocks are to be used for oxygen lines, manufacturer's recommendations should be followed as to the type of lubricant to be used. The same cocks as are specified for gas lines may be used for low-pressure hydrogen and nitrogen. Plans for hydrogen or other flammable gas distribution systems may be sent to the fire underwriters and their recommendations for installation of flash arresters or check valves should be followed.

Before placing a piping system in service it should be subjected to air or inert gas pressure of 1½ times the maximum working pressure. After a satisfactory test, a piping system for oxygen distribution should be washed out with a suitable nonflammable solution such as caustic soda or trisodium phosphate and then thoroughly steamed-out to remove all dirt and grease.

HYDROGEN SULFIDE

Hydrogen sulfide is an extremely poisonous gas with a very unpleasant odor. It is supplied in cylinders in the form of gas over liquid and has a pressure of 252 psi at 70°F. A standard cylinder will deliver approximately 1,000 cubic feet of hydrogen sulfide at atmospheric pressure. The gas is corrosive; but, because it is normally very dry, brass piping and fittings are satisfactory, although aluminum and hard rubber pipe and cocks are used extensively. A single-stage regulator with a forged brass body and steel gauge with stainless steel parts is recommended for use with hydrogen sulfide.

WASTE PIPING

Laboratory waste lines are constructed of cast iron, lead, chemical stoneware, high silicon iron, synthetic resin, or glass.

Pre-cut threaded cast iron pipe is sometimes furnished by laboratory furniture manufacturers if the normal laboratory wastes are not corrosive. Lead traps for sinks may be connected to such cast iron wastes without the use of a brass ferrule by lining a cast iron spigot fitting with sheet lead. The lead is turned back on the outside of the spigot far enough to permit making a wiped joint between the fitting and the lead trap inlet.

The use of cast iron pipe for waste connections, especially where concealed, is not recommended if acid wastes will be encountered. Its use should be avoided particularly if laboratories may be idle for long periods as in school or college buildings because corrosion is usually more severe with only occasional use.

It is well to confine the use of lead for laboratory wastes to traps and to branch connections between outlets on laboratory furniture. Lead pipe used for domestic plumbing, because it contains a small percentage of zinc, is unsatisfactory for chemical work. Chemical lead should be 99.98% pure to withstand the action of strong hot sulfuric acid up to about 312°C (608°F). Joints should either be wiped or burned. If wiped joints are used, the solder must be of satisfactory quality.

Chemical stoneware provides an excellent material for concealed waste stacks and horizontal runs, but is somewhat bulky and brittle for exposed locations. Bell-and-spigot joints in vertical lines are made by tamping one ring of asbestos rope wicking (preferably impregnated with suitable graphite or mastic) tightly into the pipe socket and then pouring melted acid-proof calking compound flush with the top of the hub. No topping off is required on vertical joints. Two rings of packing are recommended for horizontal joints. If the lines are to carry hot solutions, a topping or collar consisting of about 30% ground asbestos, 20% talc and 50% silicate of soda should be used to keep the compound from running when subjected to heat. The topping material, if stiff when applied, will set up promptly and adhere to the stoneware without trouble.

High silicon iron pipe is widely used for the disposal of corrosive wastes from laboratories, but it is brittle and care must be exercised when installing and making joints to prevent damage to the pipe. A slight space should be left between the end of the spigot and the bottom of the hub, so that metal-to-metal contact, or a joint so tight that expansion will cause strain, is avoided. Place at least two rings of pure asbestos rope packing, impregnated with graphite or mastic at the bottom of the hub and pack this tightly. The remaining space is filled with molten lead at a moderate temperature. In cold weather hubs may be preheated with a blow torch before the lead is poured.

Hemp or oakum is not acid-resisting and should not be used for packing. Dry asbestos rope does not make a satisfactory seal and should not be used.

Synthetic phenolic-resin pipe, manufactured under the trade name "Haveg", has strength, toughness and durability together with excellent corrosion-resistance. "Haveg 41" is the standard and most widely used grade and is resistant to most acids, salts, the weaker bases and many solvents. The pipe may be threaded and coupled together or furnished with bell-and-spigot ends for which joints may be made in the same manner as for chemical stoneware pipe.

"Pyrex" glass pipe is also used in some laboratories for waste lines. Important characteristics of this glass are its very low thermal expansion and excellent chemical stability. It is made in diameters of from 1 to 4 inches and in lengths up to 10 feet. The end flanges are accurately pressed pieces that are sealed to the tubing. The joints are easily made with metal flanges which are cushioned from the glass by asbestos inserts. An interface gasket of asbestos, or other suitable material, is gripped between the pipe ends when the flange bolts are tightened. There is no contact between the metal flanges and the fluid conveyed. A complete line of fittings and traps is available.

TRAPS

Laboratory waste systems are generally connected to sanitary sewers. Unless the local plumbing code permits otherwise, the waste system must comply with regulations for sanitary plumbing systems. In such cases a separate trap and vent may be required for each drainage fixture.

Laboratory wastes are generally sterile; therefore the use of a single trap for several outlets on a long bench, or even several items of equipment grouped together in one room, is frequently permitted. In some cases outlets from benches in adjacent laboratories may be connected to a single trap, but this is not good practice because it permits objectionable or even dangerous fumes to pass from one room to the other. The waste connections from equipment in the chemical laboratory of a well-known university were connected without traps to a large underground chemical stoneware collecting basin with a trapped outlet to the city sanitary sewer.

REFRIGERATION

Refrigeration may be required in a laboratory for cold storage space, process cooling, maintaining constant temperatures in special areas or for subzero testing rooms. For normal requirements a "Freon" system is preferable because there is no danger in case of leakage. A direct-expansion system will be satisfactory in most cases, but sometimes it may be desirable to use chilled water or brine.

A two-stage ammonia compression system may be required for very low temperatures. Wherever this is necessary the refrigerating equipment should preferably be located in a room with direct access to the outdoors and isolated from the remainder of the building. This location will minimize the effects of the escape of ammonia fumes. Make mains for ammonia systems of black steel pipe with welded joints and make them as short as possible. Flanged valves and fittings should be made of ferrosteel, screwed fittings of malleable iron, and flanges of forged steel, malleable iron or ferrosteel, depending on the size and style. Use iron valves with steel stems fitted with special lead or steel discs. Copper or brass is unsuitable for use with ammonia. Flanged valves and fittings should have tongue-and-groove faces to assure tightness at the joint and as an added protection against blowing out gaskets. Screwed valves and fittings should have long threads and should be recessed at the ends to permit back soldering of the joints. It is important that all valves are so designed that they can be back seated to permit repacking under pressure.

If steel pipe and fittings are used the following procedure is recommended:

1. Steel pipe must be absolutely clean. All scale and foreign matter should be removed by shot blasting before the pipe is assembled.
2. Dust remaining in the pipe after shot blasting must be removed with carbon tetrachloride and compressor oil by repeatedly pulling through the pipe a clean lintless cloth saturated with the liquid.
3. All joints must be welded. During welding, the pipe and fittings must be kept full of an inert gas,

such as nitrogen or carbon dioxide to prevent the formation of scale.

For "Freon" systems use type K or type L hard copper tubing with soldered forged or wrought copper fittings. Cast fittings may be porous and should not be used for refrigeration work. In case of emergency, cast fittings may be used if they are thoroughly tin dipped.

"Freon" valves should be back seated and provided with a cap which may be screwed on after the handwheel has been removed. This will prevent any leakage around the valve stem if the valve is only partially open.

All chilled water or brine piping should be black genuine wrought iron or steel pipe and where possible have welded joints. Fittings, where required, should be standard-weight cast iron. Valves should be gate valves as specified for cold water lines.

DISTRIBUTION SYSTEMS FOR LABORATORY SERVICES

While the present tendency is to conceal the service piping in laboratories, there are many installations where for reasons of economy or for ease in maintenance the piping is exposed. In such cases a poorly designed or carelessly installed distribution system can mar the appearance of a laboratory, but a system that is carefully planned, installed and maintained will not be objectionable.

For large multi-story laboratories a service equipment room will usually be provided on the ground floor. Starting from this point either a horizontal or vertical distribution system may be installed.

HORIZONTAL DISTRIBUTION

Risers may be run in a pipe shaft starting at the ceiling of the service-equipment room, and horizontal distribution to the various laboratories on each floor provided by mains on the corridor ceilings, or through the laboratories, adjacent to the corridor walls.

Corridor distribution is desirable unless ceiling heights are too low to enable an orderly arrangement of duct work, lights, and piping. Ducts are installed immediately below the ceiling and the service mains are installed at sufficient distance below the duct work to provide space above these mains for branch ducts and piping. Group hangers, the full width of the corridor, are spaced 10 feet apart. Steam lines and condensate lines normally pitch in opposite directions, while water, gas, air, and vacuum lines may be installed with practically no pitch. It may, therefore, be necessary to provide individual hangers for the steam and condensate lines.

Make pipe shafts sufficiently large to permit installation of all risers so that they are accessible for inspection, changes, or replacement, and provide readily accessible shut-off valves on each horizontal main near the riser. Uniformly sized metal boxes with covers on each side may be installed in the corridor walls above the mains to permit bringing services into the laboratories. The same arrangement of piping should be maintained in all laboratories and the corridor and all lines running in the same direction should be at the same level to provide an orderly arrangement where pipes must cross. Provide shut-off valves on each service just inside the laboratory. To support piping, group hangers similar to those in the corridor may be used. If possible, arrange overhead piping in the laboratories so that it does not cross laboratory tables, as dust falling off piping may ruin work on which many hours have been spent.

Either up-feed or down-feed systems may be used. With an up-feed system, connections to the laboratory equipment are brought up through the floor from the floor below adjacent to the ends of the tables or concealed in the cabinet work under the table. While this arrangement provides a neat appearance, it has two very serious disadvantages. It is difficult to locate sleeves through the floor in exactly the right position to eliminate the necessity for offsets in the piping above the floor; and also the making of repairs or changes interferes with the use of the laboratory on the floor below as well as the one for which the changes or repairs are to be made.

Where no changes are probable for several years, the distribution piping may be concealed by means of furred ceilings. In this case up-feed distribution has a definite advantage but materials and workmanship should be of the best.

Down-feed connections to equipment permit installation of the distribution piping after the equipment is in place. With proper planning and good workmanship the general appearance of the laboratory will not be marred. Lines should be spaced to allow for insulation and to permit removal or replacement of screwed fittings. Arrange valves and cocks in the drop connections to provide an orderly appearance and keep lines spaced so that by removing the working parts the bodies may be screwed in place or removed without disturbing adjacent lines.

Where several pipes are to be brought up through a floor in the same vicinity, a floor box with a split-plate cover may be used to advantage.

VERTICAL DISTRIBUTION

Some multi-story buildings have a typical arrangement of rooms and equipment on each floor, and have a basement or ground floor that will permit installation of mains on the ceiling to serve risers. In such buildings a vertical system of distribution is advantageous because a minimum amount of exposed piping is necessary. In this type of laboratory, space is provided in the corridor wall or between windows on the outside wall for the installation of concealed risers (see figure I.20). Removable panels are provided for access to these risers and to shut off valves on branch piping. Branch connections to center table, which is a peninsula and not an island, may be completely concealed, and turrets at each end of the table are provided with the necessary cocks for each service. Piping to serve the wall tables and hoods may be concealed below the top of the table or may be run exposed along the partition wall. Vertical T-slots with pipe hangers may be provided in the partition wall to support the pipes. (See p. 316 for a complete description of this type of installation.) If the depth of the laboratory rooms is great enough it may be advisable to provide risers in corridor partitions as well as in the outside wall, to serve equipment installations adjacent to these partitions. Openings for the risers may be provided in the floor slabs inside the pipe shafts, but these should be closed between floors to provide a fire stop. Some easily removable material should, however, be used so that additional risers can readily be installed.

SIZING OF LABORATORY SERVICE LINES

The proper sizing of laboratory service piping requires good judgment on the part of the engineer since the percentage of equipment served by the piping system which will be in use at any time may vary considerably. As discussed in Chapter 2, on laboratory furniture, the recommended minimum size of piping on a laboratory table is ½ inch. It is suggested that branch piping in the distribution system serving any table should be not less than ¾ inch.

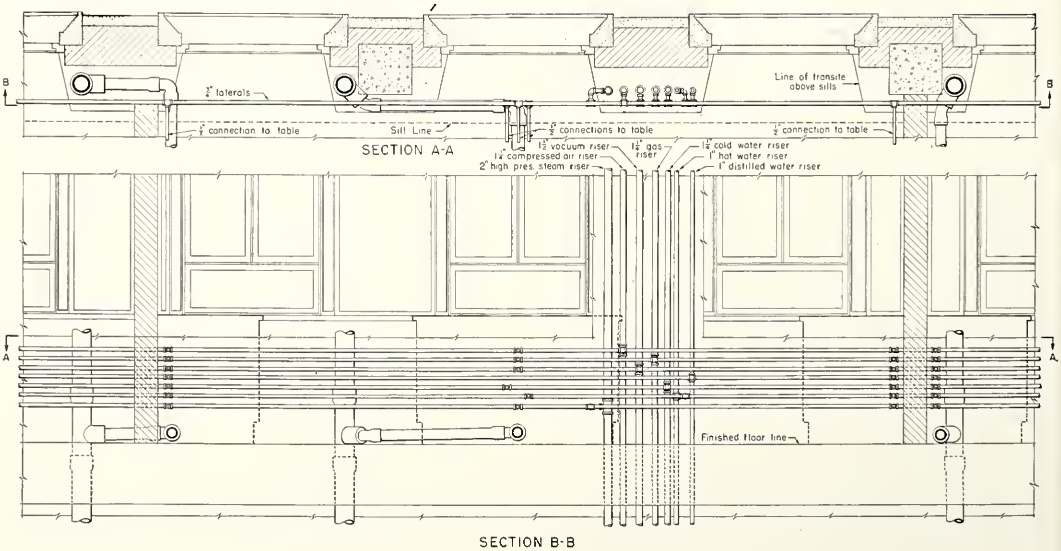
Assuming a 100% usage factor of all tables, the schedule shown in table I.1 may be used to determine the sizes of the branch lines and mains.

TABLE I. 1. NUMBER OF BRANCH PIPES SERVED BY MAIN

Size	Size Branch							
Main	½″	¾″	1″	1¼″	1½″	2″	2½″	3″
¾″	3	1						
1″	6	3	1					
1¼″	10	4	2	1				
1½″	16	6	3	2	1			
2″	32	12	6	3	2	1		
2½″	56	20	10	6	3	2	1	
3″	88	32	16	9	6	3	2	1
4″	180	66	32	18	12	6	3	2
6″	500	180	88	50	32	16	9	6

Thus, if in a single room there are four tables each with a ½ inch gas line, a 1-inch branch service line into the room will be adequate. If there were six rooms of this size to be served, a 2-inch main would be more than adequate. Since it is very doubtful if more than 60% of the cocks would ever be in use at the same time, a 1½ inch main could in this case be provided.

Figure I.20 A vertical distribution system of pipe services designed for laboratory tables.



While theoretically the size of the main might be reduced as connections are taken off, the saving in cost would be very small and the pressure at the far end would be improved by keeping uniform the size of the main.

Suggested Markings for Laboratory Services

All exposed distribution lines for laboratories should be of some light color such as cream or white, or to match adjacent building surfaces. Provide these lines with colored bands at approximately 10-foot intervals, and immediately before and after passing through floors, walls or partitions and at each change in direction in accordance with the schedules indicated in Table I.2. Piping and conduit on laboratory tables and benches should be painted with the same markings in not less than two places. All cocks and valves should have index buttons of the proper color or be otherwise permanently finished in the corresponding colors with markings as noted.

TABLE I. 2.

Service	Color	No. and type of bands	Cocks and valves
Fire protection	Red all over		
Steam, HP	Orange	2 wide bands	SH
Steam, LP	Orange	1 wide band	SL
Condensate	Orange	1 narrow band	—
Water, hot	Green	2 wide bands	HW
Water, circulation	Green	1 wide band	—
Water, cold	Green	1 narrow band	CW
Water, distilled	Green	2 narrow bands	DW
Water, deionized	Green	3 narrow bands	dW
Compressed air, HP	Aluminum	2 wide bands	AH
Compressed air, LP	Aluminum	1 wide band	AL
Vacuum	Aluminum	1 narrow band	V
Gas	Bronze	1 narrow band	G
Hydrogen	Bronze	2 narrow bands	H
Oxygen	Bronze	3 narrow bands	O
Nitrogen	Bronze	4 narrow bands	N
Hydrogen sulfide	Bronze	5 narrow bands	HS
Carbon dioxide*	Red	6 narrow bands	CO_2
* For fire protection service.			
Electricity	**Color**	**No. and type of bands**	**Outlets**
DC110v	Blue	1 wide band	DC-1
DC220v	Blue	2 wide bands	DC-2
AC110v	Blue	1 narrow band	AC-1
AC-220v	Blue	2 narrow bands	AC-2
AC-440v	Blue	4 narrow bands	AC-4
AC-550v	Blue	5 narrow bands	AC-5
Refrigeration	**Color**	**No. and type of bands**	**Outlets**
Liquid	Black and white	1 narrow band each	—
Gas	Black and white	2 narrow bands each	—
Chilled water	Black and white	1 wide band each	—
Brine	Black and white	2 wide bands each	—

5

SECTION 1: LABORATORY LIGHTING

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Laboratory lighting requirements have much in common with certain classes of interiors for which the Illuminating Engineering Society has recently produced detailed standards of practice. Thus the reference data compiled for Office Lighting*, and for Classroom Lighting†, cover a majority of the problems which may occur in laboratories. Reference data on industrial lighting can fill in at most instances not otherwise covered by the two other fields‡. To be sure, in the broadest sense, laboratories include types of interiors which do not fall clearly in the office or classroom or industrial category. This does not matter greatly since lighting practice aims primarily at seeing tasks. The Illuminating Engineering Society's standards of practice for offices and classrooms emphasize this primary objective. The name laboratory, it may be observed, is a term used by a scientist for the place where he works. He may on occasion, if his work is with a business or an industry, call this space his office. If his work is with a school or college he may refer to the place as a classroom or a workshop. Lighting practice, directing its main attention to tasks for the eyes, takes care of special characteristics of various structures as an incident of the main objective. Thus, most fields of practice have more things in common than differences.

Industrial lighting has been moving rapidly in recent years to the refinements of office lighting. It has been pointed out that relative to the average investment per worker industrial practice can support the advanced practice more logically. Of course, there are special situations and conditions in industrial laboratories which defy the trend to refinements. But the lighting problems here are, as they are elsewhere, related to the seeing tasks.

Since this report deals with the general rather than the special aspects of laboratory lighting the recent reports on office and classroom standards plus IES Handbook data on Industrial Lighting will provide its main elements.

The purpose of lighting is to provide efficient and comfortable seeing as an aid to laboratory operation and the conservation of vision. Illumination is good when it is suitable in quality and quantity for: 1. creating general environmental brightnesses agreeable and beneficial to the user, and 2. permitting a high degree of efficiency in seeing the necessary tasks with a minimum of effort. It is important, therefore, to analyze the controllable factors which contribute to seeing: the *task*, the *lighting*, and the *environment*. In practice these factors are closely interrelated.

In modern laboratories as in office operations and to a lesser degree in classrooms, the eyes are often used at close range for severe visual tasks such as reading duplicated material, handwriting, penciled stenographic notes, typing and fine print. The visibility of such work is often poor.

Satisfactory seeing requires not only a comfortable visual environment but also suitable visibility characteristics of the tasks. In laboratories the eyes are not only used for closeup visual tasks but for other tasks involving relatively more distant viewing such as chalkboards.

The visibility of a task or object is determined by its *size*, *contrast* with background, *brightness*, and *time* of viewing. Each factor is sufficiently dependent upon the magnitude of the others that a deficiency in one, within limits, may be compensated by augmenting one or more of the others. Only the factors of *size* and *contrast* are inherent in the task itself.

The amount of light necessary for optimum performance of laboratory tasks is often more than economically justifiably today even with the most efficient sources and the most effective lighting systems. The values should be commensurate with the difficulty of the various seeing tasks, higher for such work as is encountered in work analagous to drafting, designing, bookkeeping and various machine operations than for the more casual or intermittent tasks. The former involve prolonged work periods with tasks of fine detail and poor contrast (see table I.3).

A new laboratory building erected near Schenectady by the General Electric Company has an advanced fluorescent lighting system. H. H. Race has reported* on the new system as follows:

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* Illuminating Engineering—July, 1947.

† Illuminating Engineering—September, 1948.

‡ IES Lighting Handbook.

Discussions with our own personnel and with lighting experts resulted in the following conclusions:

A. Lighting at the work benches should be about 50 footcandles.
B. Diffused light giving a good intensity of illumination on vertical surfaces so as to make it easy to read instruments such as meters, manometers, pipettes, and the like.
C. Fluorescent lamps are preferable to incandescent lamps because they provide diffuse light sources and also because they provide more lumens per watt and therefore more light per operating dollar.
D. Electrical interference with high-sensitivity electronic equipment does not prohibit the use of fluorescent lamps because the operation of oscillators of various frequencies throughout the laboratory forces the general use of shielded cages for high-sensitivity apparatus.

The most important new feature of this installation is that 5-foot (40-watt) low-intensity lamps are used throughout, thus minimizing the sensation of glare in the room.

A trial installation (of recessed aluminum troffers), in operation for about two years, pre-tested the system. The recessed *single-lamp* troffers are made of aluminum with an "Alzak" finish which has a semi-mat surface to avoid producing specular reflection and to provide considerable light diffusion. The troffers are 12 inches wide, and five units end to end occupy 25 feet out of the 26 feet clear distance from the inside surface of the outside wall to the room side of the shaft covering. The center lines of these lines of units are placed 3 feet apart and midway between possible partition positions.

The 3-foot lamp module is consistent with the partition, window, and door modules. The lines of lamps will be in the same relative position with respect to cross partitions regardless of which partition position is chosen. Also, there will always be a line of lamps over benches or work tables along the partitions so that persons conducting experiments on these benches will not be working in their own shadows.

In the trial installation, the lighting at bench height after two years of lamp operation is 50 footcandles. The energy required to produce this illumination is less than 3 watts per square foot of floor space. Furthermore, the illumination is so diffused and free from glare that it has been found unnecessary to use baffles in the light troffers; and the general level of illumination has been so adequate as to make unnecessary the installation of desk lamps in this office. The occupants of the room are very pleased with the lighting installation.

TABLE I. 3.—RECOMMENDED VALUES OF ILLUMINATION

These recommendations are commensurate with the difficulty of the various groups of seeing tasks and the current general cost of lighting. The values should be *maintained* in service through proper cleaning of lighting equipment, replacement of depreciated or failed lamps, and maintenance of room surfaces. Initial values will have to be greater by a percentage sufficient to compensate for the depreciation expected.

	Footcandles [current recommended practice]
Difficult seeing tasks involving: a. Discrimination of fine details such as 6-8 point type b. Poor contrast c. Long periods of time such as: Designing Drafting Transcribing and tabulation Machine operation Bookkeeping	50
Ordinary seeing tasks involving: a. Discrimination of moderately fine detail such as 8-12 point type b. Better than average contrast c. Intermittent periods of time such as: General laboratory work (except for work coming under "Difficult seeing tasks" above) Private office work General correspondence Conference rooms Active file rooms Mail rooms	30
Casual seeings tasks such as: Inactive file rooms Reception rooms Stairways Washrooms, and other service areas	10
Simple seeing tasks such as: Hallways and corridors Passageways	5

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* General Electric Review, November, 1948.

The B. F. Goodrich Company's new Research Center, opened at Brecksville, Ohio, in 1948 has an outstanding fluorescent system. H. N. Stevens, Research Coordinator, describes it as follows:

"All laboratory and office areas are illuminated by 2-lamp instant-start, 4500 white, 40-watt fluorescent fixtures with illumination of about 40-50 footcandles. Single tube fixtures using the same lamps are used in corridors, with egg-crate shielding. Corridors have illumination of about 20 footcandles. The library and auditorium are illuminated with indirect fluorescent systems.

"The scientists have been delighted with the lighting arrangements throughout the whole laboratory. Of particular importance has been the freedom from shadows in all work areas and the satisfactory level of illumination."

CAUSES OF GLARE

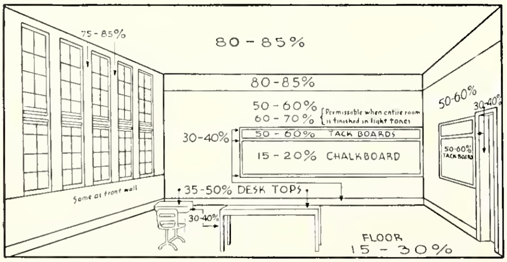
Glare, which results in reduced visibility and in visual discomfort is caused by high brightness and large brightness differences anywhere in the visual field. When the condition is caused directly by the source of the lighting, whether natural or artificial, it is described as direct glare.

Unshaded windows are a frequent cause of direct glare. They permit direct view of the sun, bright portions of the sky and the brightness of adjacent buildings. These often constitute large areas of very high brightness in the normal field of view. The condition may be controlled by shading the windows with various shade, blind, louver or baffle systems.

Lighting luminaires which are too bright for the environment in which they are located produce direct glare. The eyes are quite susceptible to glare in the zone from the normal line of sight, which seldom is higher than horizontal to about 45° above. It is recommended that luminaires have low brightness in the shielded zone as illustrated (see figures I.22, I.23 and I.24).

The brightness of the luminaire should be kept as low as possible. Ideally it should have the same brightness as its background. This, however, is generally approached only with a few restricted types of luminaires of the general semi-indirect type. Experience indicates that louvered luminaires having brightnesses as high as 2,400 footlamberts in the 0-45° zone are acceptable when the horizontal work surfaces are mat and the work is not specular. Where the work has a high degree of specularity, brightnesses in the 0-45° zone should be considerably less than 1,000 footlamberts. For very large rooms where luminaires would occupy a large portion of the field of view, brightnesses in the 75-90° zone should be kept substantially below 225 footlamberts. Figure I.21 indicates the range of reflectances permissible in a classroom. The same figures apply for much laboratory lighting.

Figure I.21 shows the range of reflectances recommended in a schoolroom. The same range applies in the design for much laboratory lighting.



Deficiency in lighting quality is usually caused by glare or brightness differences which are uncomfortable and often harmful. Moderate deficiencies are not readily detected, although the cumulative effect of even slightly glaring conditions results in loss of seeing efficiency and undue fatigue. The sense of glare is determined largely by the brightness ratios or differences in the field of view.

UNIFORM ILLUMINATION

Evenly distributed illumination is desirable for most laboratory tasks. It permits flexible arrangement of operations and equipment and helps assure more uniform brightnesses throughout the area. While light from one direction has value in emphasizing contour, well distributed lighting from all overhead directions is required in most cases. Its use results in the elimination of objectionable shadows and in more uniform illumination. To accomplish this a number of sources or large luminous areas is required. Lighting equipment must be spaced in keeping with its light distribution characteristics and the physical characteristics of the room.

Shadows on work surfaces are annoying and may contribute to considerable fatigue. Illumination must be diffused to minimize shadows. Elimination of shadows can rarely be accomplished, but care should be taken to reduce the density and sharpness of any present. High reflectance mat finishes on room surfaces become effective secondary light sources and reduce the annoyance of shadows by reflecting a significant amount of diffused light.

The eyes function most comfortably and efficiently when brightnesses within the entire field of view or environment are uniform. It is not practical to achieve complete uniformity but it is desirable and practical to reduce the extreme brightness differences.

No surface in the laboratory is more important visually than the desk or tabletop. For a person working at a desk, the top occupies most of the visual field. The task is usually of high reflectance and in order to provide comfortable seeing, desk tops in related reflectance values are required. Reflected glare is eliminated for practical purposes if the surfaces are mat as well as of recommended reflectance.

The color and reflectance of room walls, ceilings and floors as well as room proportions have their effect upon the utilization of light. Room surfaces act as secondary light sources of large area and, from the standpoint of *efficiency*, high reflectance finishes are preferred.

The following recommendations establish approximate reflectances for good brightness ratios in laboratories which correspond to the office or classroom environment:

Ceilings	85%
Walls	60%
Desk tops	35%
Furniture	35%
Floors	30%

This recommendation for ceilings permits the use of white or off-white, yellow, ivory and cream tints, but precludes most green, blue and more saturated colors. Acoustic tile and plaster have sound-absorbing holes or cavities which also absorb light. To compensate for the inherent light-absorbing characteristics of these materials, high reflectance white finishes are usually necessary to meet the reflectances recommended. Ceilings reflecting from 75% to 85% of the light striking them are essential for good efficiency with indirect lighting and for reduced brightness ratios between luminaires and the ceiling with direct lighting systems.

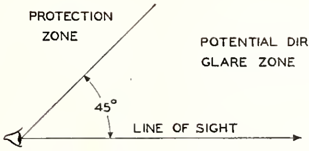


Figure 1.22 The eyes are susceptible in varying degrees to direct glare in the zone from the line of sight to about 45° above.

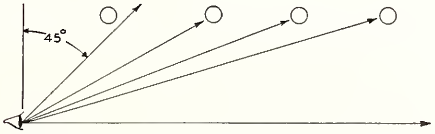


Figure 1.23 There are many positions where luminaires may cause direct glare; the normal line of sight is seldom higher than horizontal.

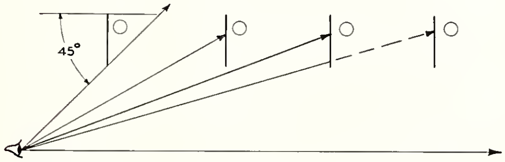


Figure 1.24 To protect the eyes in the potential direct glare zone, luminaires should be shielded to about 45° as illustrated.

ENVIRONMENTAL CONTROL

Color should be used to make the working environment interesting and pleasant. Cream, ivory and buff seem warm and they may make an area appear smaller. On the other hand, a room may be made to appear larger and cooler by selecting colors such as light tints and pastel shades of green, blue-green and blue which seem to recede. Gray finishes are neutral and excellent for either the background or for furniture and machines. The use of gray for both, however, can be very monotonous and result in a dull and unsatisfactory environment.

For most laboratories, artificial lighting, either filament (incandescent) or fluorescent lighting can provide good solutions. Filament lamps produce a distinctly warm yellow-white light (2800°). Fluorescent lamps are available in similar color quality in the standard warm white lamp. The standard cool white (4500°) lamp with its stronger blue-white character offers a good all-around choice for general illumination purposes. For more particular problems of color rendition, where food, fabrics, or complexions are involved, the de luxe warm white and the de luxe cool white lamps offer important advantages. For laboratory work involving special color discrimination the spectral characteristics of the de luxe cool white lamp would probably be the best choice.

One sees equally well under the same illumination value of comparable diffusion and directional quality from either filament (incandescent) or fluorescent lighting. However, the two illuminants work out quite differently in such matters as initial cost, operating economy, heat, wiring requirements and general appearance. For example, filament lighting is usually simpler to install. This is one aspect of its generally lower initial cost. Against this, however, is its inherently higher operating cost with reference to a comparable fluorescent system. The wattage required is approximately three to four times that of such a fluorescent system. This wattage requirement may involve rewiring. Then, too, because filament lighting is so often used in semi- or totally indirect systems, the delivered illumination is much more dependent upon maintenance of ceiling and wall surfaces. This is a further factor of increased operating cost.

The quality and general appearance provided with good semi- or totally indirect filament lighting can be very satisfactory. It must be kept in mind, however, that as illumination values exceed 40 footcandles limitations of associated heat and brightness ratios must be considered.

Fluorescent lighting, although initially more expensive to install, has greater overall economy to offer. Methods of application usually chosen for it (chiefly direct lighting) emphasize this economy.

COLOR AND COLOR QUALITY

The colors of light sources may produce very definite psychological reactions. Daylight lamps, for instance, provide high illumination without developing a feeling of heat and high brightness. Conversely, the use of daylight quality light sources, to provide low values of illumination, may result in a dull and gloomy appearance while sources of warmer character will usually be satisfactory in this regard.

For most visual tasks, it appears that with equal quantities of illumination, minor variations in color quality have little or no effect upon the clearness and quickness of seeing. If recommended reflectance values are followed, tints and pastels are indicated and no problem of color fatigue will be encountered. Colors for light sources and for room, furniture and equipment finishes may be selected primarily for their aesthetic and psychological values.

Seeing comfort, the goal of lighting design, is influenced by room and furniture finishes. In conjunction with the lighting system they determine the brightness pattern of the room environment and the relation between it and the task brightness. The room finishes, especially those on the ceiling, are important factors in determining the brightness ratios between the lighting equipment and its surroundings. The use of light-colored matte finishes for all laboratory surfaces helps to achieve the objectives of comfort.

DAYLIGHTING

Windows serve two purposes in the lighting of laboratories. First, they admit light into the area; second, they permit occupants to "look out" of the office into the broader vistas outdoors. In addition to the psychological, there is a definite seeing advantage in being able to achieve distant vision because certain muscles in the eyes relax only when seeing distances are on the order of 20 feet or more.

Unfortunately, the glare from window areas frequently offsets these advantages. Care should be used in obtaining the maximum benefit from windows without introducing objectionably large areas of high brightness into the seeing environment.

The distribution and amount of daylight admitted to an interior will depend upon the type of glass; the size, shape and position of the window openings; the ratio of window area to floor area; the ratio of the height of windows to the distance from the opposite wall; the window shades; the presence of outside illumination; and other outdoor conditions such as sun position and cloud formations. Many of these factors can be set for maximum lighting and seeing comforts. However, the source of illumination is changing constantly and the illumination within an office varies with weather conditions, the time of day and the season of the year.

Clear plate or window glass are the usual materials for windows. They are usually more effective than the various kinds of fluted, ribbed and diffusion-type glasses in distributing light throughout the room, although special prismatic light-directing glass blocks are efficient for exposures receiving direct sunlight.

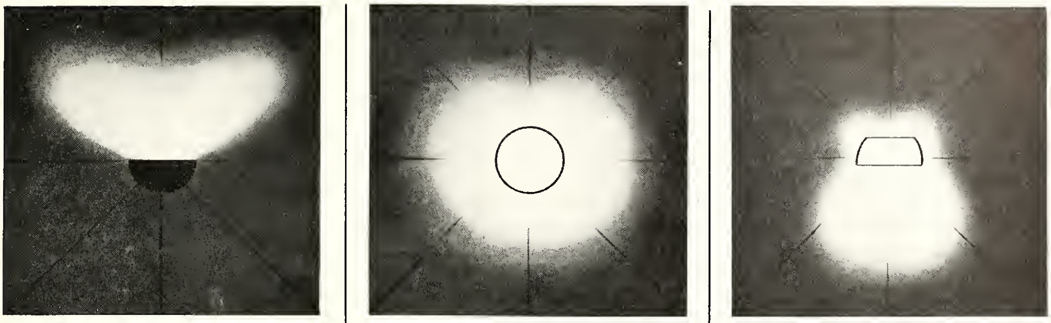
Since it is the upper portion of the window that controls the light introduced into the deepest portions of the room, the top window sections should be as close as possible to the ceiling. The ratio of the height of the top of the window above the floor, to the room dimension perpendicular to the window wall, should be at least 0.5. The uniformity of illumination becomes rapidly worse at ratios less than 0.5 and is not appreciably affected by ratios greater than 0.6. The glass area should utilize as much of the outside wall as practicable, favorable ratios of glass area to floor area ranging from 0.15 to 0.25.

Unfortunately, the upper portions of windows that are most effective in improving uniformity of illumination with daylight, are also the most detrimental as far as direct glare is concerned. The sun, sky and clouds are generally the brightest elements in the outdoor brightness pattern. Consequently, office occupants should be seated so that windows are not in their field of view but also positioned so that they do not cast shadows on their work.

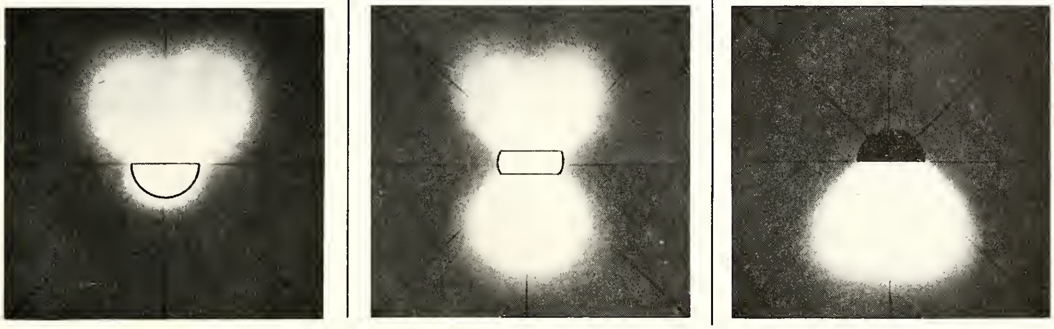
Window shades, louvers or baffles may be used to protect laboratory occupants from direct glare and permit greater freedom in personnel orientation. The type of these devices and the way they are manipulated has a marked effect on the distribution of daylight illumination. Shades transmitting diffusely a large part of the natural light will generally improve the daylight illumination, but may of themselves become objectionably bright and glaring. Louvers or venetian blinds employing reflecting and diffusing surfaces are an effective means for controlling the distribution of natural illumination as well as the glare from windows. Care must be exercised to insure their proper adjustment for both maximum utilization of lighting and protection from glare. Light tones and finishes are desirable on shades and louvers so that they effectively reflect not only daylight, but also artificial light which must be used when daylight fails.

Dirt Collection on Windows—As windows accumulate dirt, their efficiency for transmitting light decreases rapidly and because of the diffusing characteristics of the dirt, the windows become glaring.

Psychological Value of Windows—Since the lower portions of windows are not effective in producing uniform lighting into the far areas of the room, clear plate or window glass is desirable. These materials have the desired property of allowing laboratory workers to look at distant objects, thus releasing accumulated eye muscle tension. This feature is especially helpful in the



Indirect **Diffusing Enclosure** **Semi-Direct**



Semi-Indirect **Direct-Indirect** **Direct**

Figure I.25 Types of lighting systems.

small room where the degree of distance accommodation is small. Although windowless areas can be made comfortable and efficient, the opportunity to see the outdoor landscape seems psychologically desirable for most persons.

ARTIFICIAL LIGHTING SYSTEMS

For constant and more nearly uniform seeing conditions, artificial lighting will probably be required. Such lighting may be accomplished with any of several types of systems, some of which are more desirable than others. The performance of each should be evaluated in terms of:

A. Function—Does it provide lighting to meet the basic needs of comfortable laboratory seeing?
B. Appearance—Are the size, shape, color and texture of the equipment and its component parts in keeping with the architectural and decorative design of the area?
C. Cost—Is the cost, not only of initial installation but also of operation and maintenance, commensurate with the return to be realized in efficient operation and eyesight conservation?

Types of Lighting Systems

General—Most lighting systems are included in one of the following five classifications (see figure I.25). These comments refer specifically to applications in laboratories of the office-classroom type.

Indirect—With this system 90% to 100% of the light from the luminaires is first directed to the ceiling and upper sidewalls from which it is reflected to all parts of the room. With the ceiling becoming, in effect, the light source, the diffused quality of the illumination minimizes shadows and reflected glare. Care must be taken to keep the ceiling brightness low enough to prevent its being a source of glare.

Because room finishes constitute an important part of indirect lighting systems, careful attention must be paid to having them as light in color as possible and to maintaining them in good condition. They should be mat, as well as high reflectance finishes.

Opaque or translucent luminaires and architectural coves are the most common methods employed for indirect lighting. Low ratios of ceiling to luminaire brightness are desirable.

Semi-Indirect—These systems emit 60% to 90% of

Figures 1.26 and 1.27 Views of single lamp, low brightness 40-watt recessed troffers in new General Electric Laboratory. Rows are on 3-foot spacings.

the luminaire output upward toward the ceiling and upper side walls while the rest is directed downward. Since this lighting also utilizes the ceiling as the main source of light, the same considerations as for indirect lighting should be observed with regard to ceiling finish and good maintenance.

In general, semi-indirect units are characterized by luminous surfaces which may help achieve desirable brightness ratios with the ceiling, but as the downward component increases, the factors of direct and reflected glare may require attention.

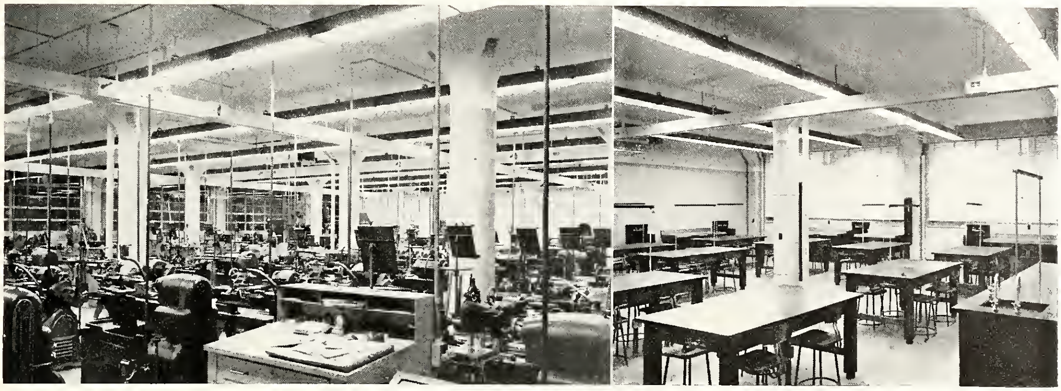
General Diffuse or Direct-Indirect—This classification refers to systems where the direct and indirect components are about equal and the resulting illumination is predominantly from the downward component. There are two types of units included in this classification. The general diffuse distribute light about equally in all directions while the direct-indirect produce little light in angles near the horizontal. The latter are, therefore, usually more suitable.

With these systems shadows are more noticeable and some difficulty may be experienced with direct and reflected glare.

Semi-Direct—In this classification, 60% to 90% of the luminaire output is directed downward toward the work surface. The small upward component illuminates the ceiling reducing the brightness ratio between the luminaires and the surroundings. Luminaires of this type have reflecting surfaces above the sources which produce the predominantly downward component. Glass or plastic enclosures or louvered bottoms provide diffusion and shielding.

Direct—Units in this classification are defined as those which direct practically all (90% to 100%) of the light downward with minimum losses on ceiling and sidewalls. The directional characteristics of this type of lighting may produce disturbing shadows unless the units are of large area or are closely spaced. Undue glare and high brightness ratios may be minimized by reducing the brightness exposed to normal view and by illuminating the ceiling through the use of room and furniture surfaces of high reflectances.

Summary—No one system may be recommended to the exclusion of the others. For instance, indirect lighting inherently provides excellent quality on th work but with moderate to low utilization. Direct ligh ing is characterized by good utilization but the quality of illumination required by laboratory tasks is obtained only if precautions are taken to use close spacing or large-area low-brightness equipment. Intermediate systems combine the characteristics and therefore advantages or limitations of direct and indirect lighting in varying degrees.



Figures 1.28 and 1.29 Views of continuous row system of industrial units, Rochester Institute of Technology.

MAINTENANCE

Lighting equipment and room surfaces must be well maintained if reasonable efficiency and satisfactory appearance are to be realized. The elements which affect the overall efficiency of a lighting system are the light sources, the luminaires and the room surfaces. Depreciation of 30% to 50% may be expected depending upon decrease of lamp light-output, atmospheric dust conditions, and design of luminaire in relation to dirt collection.

The output of all light sources diminishes with use and, in many cases, it is economical to replace lamps before they finally fail. With planned lamp replacement schedules, savings are realized by replacing groups of lamps rather than individual ones, and depreciated lamps are replaced by those of peak performance. If lamps are replaced in alternate luminaires or in alternate rows of luminaires, more constant illumination is maintained.

Lamps and lighting equipment collect dust and dirt which reduce lighting efficiency. The rate of depreciation is dependent upon the atmospheric conditions and the type of lighting system employed. A thorough washing of lighting equipment at least twice a year is economically justified in even the most favorable locations. Under adverse conditions, three or four cleanings are needed to achieve the lowest cost operation in terms of footcandle hours per dollar. With proper cleaning schedules, an increase of at least 25% is often realized in the average maintained value of illumination. Lighting units should be selected with minimum depreciation characteristics and easy maintenance features.

The necessity for cleaning or painting room surfaces is also a function of the amount of dirt contained in the atmosphere. The rate of depreciation is materially reduced where air-conditioning and filter systems are employed, but it is very difficult to eliminate dust and dirt entirely in laboratory work areas. The distribution characteristics of the lighting system also influence the effect of room maintenance, since dirt on room surfaces is more detrimental to an indirect than to a direct lighting system.

A regular program of window cleaning is also essential. Although the accumulation of dirt may not be as rapid in laboratory buildings as in factories, the windows require frequent washing to maintain them at reasonable efficiency. Dirt on the inside and outside of windows frequently absorbs as much as 50% of the light that might otherwise be admitted to the laboratory. At the same time, the diffusing effect of such dirt can result in very high brightness at the windows and can produce serious direct glare.

A realistic consideration of these various factors is essential to the efficient operation of a satisfactory lighting system. The cost of even frequent maintenance is more than offset by the value of the additional illumination obtained.

REPORT ON BRIGHTNESS AND BRIGHTNESS RATIOS

General

Frequent reference is made to the desirability of providing more nearly uniform brightness in the visual field. The following section of the Report No. 1 of the Committee on Standards of Quality and Quantity for Interior Illumination of the Illuminating Engineering Society is an authoritative summary of many researches pertaining to this subject.

Brightness Ratios in the Visual Field

The effect of the brightness of a light source or of a luminous portion of a luminaire upon visibility, comfort or ease of seeing depends largely upon the ratio of that brightness to that of the background against which it is seen. Similarly, the effect of the brightness of the immediate surroundings of a visual task (such as this printed page) depends upon the ratio of the brightness of the task to that of its surroundings. Therefore, the specification of brightness ratios is a basic necessity. The results of extensive researches reveal the proper brightness ratios in the visual field where critical tasks of seeing are performed for prolonged periods. The following specifications are for relatively large areas and do not involve purely aesthetic considerations.

Brightness Ratios to Attain Best Seeing Conditions

The ratio of the brightness of the visual task to the brightness of its immediate surroundings is unity. The effect of any portion of the surroundings decreases as the angular distance with the line of vision increases. There is no sharply defined boundary between the immediate surroundings and the outer peripheral visual field. However, the surroundings in this case should have a reasonable angular extent and might well be considered to extend to 30° from the line of vision in all directions.

GENERAL LIGHTING IN INDUSTRIAL LABORATORIES*

Modern industrial lighting practice is to provide a uniform illumination level throughout every work area. This is called general lighting. The general-lighting level should be uniform so that light will be available, when needed, at any point. This is particularly desirable for interiors where the layout may be changed. If the general lighting has been designed for uniform illumination, tables, machines, and other equipment often may be moved without necessitating a change in lighting installation.

The purpose of a general-lighting system where there is also supplementary lighting is to keep the brightness ratios between the task and the surround within a range that is comfortable to the eyes (not over 10 to 1) in order to provide sufficient light for safety and to illuminate secondary visual tasks.

Layout Suggestions

The conventional arrangements of electrical outlets for lighting (one, two, or four per bay) have been adequate for a wide range of footcandles because of the many incandescent-filament lamps available in the 150- to 1,500-watt range with outputs of from 2,600 to 33,000 lumens each. By comparison, the fluorescent-lamp range, encompassing only a few ratings between 15 and 100 watts with outputs of 495 to 4,400 lumens each, is limited. To obtain a lumen output per fluorescent luminaire comparable with that of a 500- or 1,000-watt, incandescent-lamp luminaire, it is necessary to use many lamps.

Fluorescent lamps, by virtue of their tubular form, suggest new layout and installation methods: continuous rows of lamps and "troffer" systems. Since the lamp lengths and ballasts are different for each of the fluorescent lamp sizes, these lamps are not interchangeable. However, future increases in illumination may be provided for by a wiring layout that will accommodate added luminaires or rows of luminaires to co-ordinate with the original installation. It is possible, also, in some two-lamp luminaires to add a third lamp of the same size, with an increase in illumination of approximately 50%. Where such luminaires are spaced closely, or in continuous rows, the two extra lamps in adjacent luminaires can be served from a two-lamp ballast located in one of them.

Mounting Height

Spacing between luminaires usually should not greatly exceed their mounting height. For practical purposes the average illumination level produced by general-lighting installations of spread distribution luminaires in large areas is independent of luminaire mounting height. In small areas the average varies in proportion to the coefficient of utilization, not inversely with the square of the distance from luminaires to illuminated plane.

Supplementary Lighting for Industrial Research

Extremely difficult seeing tasks require illumination levels which are not always easily or economically obtained by standard general-lighting methods. To solve such problems supplementary luminaires often are used to provide high levels for small or restricted areas. Also, they are used to provide a certain brightness or color, or to permit special aiming or positioning of light

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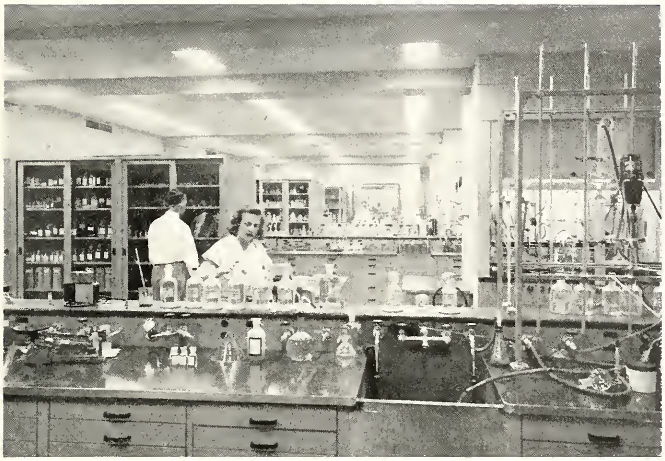
* Selected from the "IES Lighting Handbook."



Figures 1.30 and 1.31 Views of recessed troffer units, B. F. Goodrich Research Center.

sources to avoid shadows caused by technicians or machinery. A reasonably comfortable interior usually results when the general-illumination level is at least one-tenth that of the supplementary level. Technicians using their eyes for critical visual tasks glance away from their work at frequent intervals for momentary relaxation. If the brightness ratio between task and surroundings is too great, instead of being rested, the eyes are fatigued.

Supplementary Luminaires

Two types of supplementary equipment will take care of almost all requirements: 1. Small, concentrating projectors augment the general lighting on a seeing task and provide directional quality. 2. Large-area, low-brightness diffuse sources may provide either general lighting for small areas or "plus" lighting for a more difficult seeing task such as inspection. All supplementary luminaires and projector lamps should be shielded, louvered, or mounted so as to minimize the possibility of glare. Where fluorescent luminaires are used, they should be of the two-lamp type to minimize stroboscopic effects.

Portable Luminaires

Portable equipment, such as that used to good advantage in airplane hangars and garages and wherever internal surfaces must be viewed, is available. A typical unit consists of five angle-reflector luminaires mounted on a portable rack with outlets for electrical tools. Lamps with self contained control such as the R-30 and R-40 types, and the rugged PAR-38s often offer the simplest solutions. Two-hundred-watt, inside-frosted incandescent lamps are recommended where separate reflectors are used. A "trouble light" consisting of 50- or 100-watt rough-service lamps in a guarded socket attached to an extension cord often is provided for internal inspection. Similar devices have been developed for fluorescent lamps.

Hazardous Locations

Vapor-proof, explosion-proof, and dust-tight luminaires each are designed for a specific type of location where either corrosive vapor, flammable gases, or explosive dusts are likely to be encountered from such processes as oil refining, paint and varnish making, or lacquer spraying. Special equipment such as this usually is mandatory also in locations with moisture-laden atmospheres such as steam processing, engine rooms, and shower baths. The National Electrical Code requires the use of these special types of luminaires in certain areas. Both angle and symmetrical types of reflectors in the 75- to 500-watt size range are used. Equipment employing fluorescent lamps for this service is also available.

LIGHTING FOR INDUSTRIAL INSPECTION

In most production processes there are one or more inspection operations that involve checking some characteristic of a material or product against a previously established specification or standard. Although inspection or checking sometimes is accomplished by the use of devices requiring little visual effort or skill on the part of an operator, acceptance or rejection often depends on the accuracy of the visual observations of a skilled inspector. Usually, because of the importance of the inspector's decisions in such cases, it is worth while in planning a lighting installation to treat an inspection area as a special problem. The following examples suggest ways in which a variety of typical inspection problems have been solved.

Highly Polished Surfaces

Chrome or tin plate, aluminum sheet, and other specular surfaces frequently are inspected visually to detect scratches, dents, bare spots, and other flaws. It has been found that an inspector can locate such flaws when he views an image of a low-brightness luminaire in the polished surface. The image should be at least as large as the area to be inspected and its brightness should be not more than 400 footlamberts. (Surround brightness should be not less than 1/10 image brightness.) The area to be inspected should be so screened that images of other sources, windows, machinery, or personnel are not in the inspector's field of view.

Opaque bands of uniform width equally spaced in parallel lines, rectangular grids, or concentric circles are of assistance in detecting surface contour irregularities. These are revealed by a distortion of the image pattern which in some cases may be noticeable only when the inspector moves his head.

Printers' imposing stones, type composition cases, and metals used for scribing present similar seeing problems which may be solved in this manner.

Refractive flaws in transparent materials may be detected by viewing the image of such a source or the source itself through the material.

The following rules of thumb are applicable in a typical inspection process for plate glass:

A. The glass should be viewed against a combination of light and dark areas.

B. The light source should have a brightness of less than 1,800 footlamberts (4 candles per square inch).

C. The light source preferably should be rectangular in shape with a width of 5 to 6 inches and a length of 24 to 30 inches. With luminaires of this size the width of the dark spaces between should be of the order of 2 to 3 feet.

Trough-shaped luminaires are located approximately 6 feet behind the support for the glass plate. The supporting framework for the glass plate should be raised or lowered to bring the glass area between the eyes of the inspector and one or more of the luminaires.

Open-weave Fabrics and Other Translucent Materials

The location and removal of any defects in open-weave fabrics previous to the final finishing process is accomplished best by observing the defects in silhouette against a large-area, uniformly low-brightness panel. The brightness of the panel should be sufficient to show up defects. It should not exceed 400 foot lamberts. The surround brightness should not be less than 1/10 that of the panel. For the best silhouette vision the illumination on the cloth from the observer side times the reflectance of the cloth should be not more than one-tenth the brightness transmitted by the cloth.

Light transmitted through translucent materials such as glass, paper, plastics, and liquids also may reveal certain kinds of faults, foreign material, and defects. Large luminous panels can be built in conveyor lines over which, or past which, the material flows. The illumination level required varies with the task. A panel brightness of the order of 100 footlamberts often is adequate. Bubbles, blisters, cracks, chips and whorls may be revealed as highlights or distortions caused by refraction when transparent materials such as glass jars, bottles, bulbs, and clear plastics are seen moving before a large-area, low-brightness panel. Alternate dark and luminous backgrounds or black strips laid on a luminous background aid in locating and identifying defects.

To detect small fire cracks and bubbles in glass jars and the pin-point bubbles caused by foreign material in carbonated beverages, a narrow beam source is recommended. The mirror action of these defects reveals their presence.

A modification is the arrangement employed for the inspection of inner tubes for air leaks. The partially inflated tubes suspended from an overhead conveyor are passed through a trough filled with water under the surface of which there are light sources on each side of the inspector's stand. Any air bubbles coming from the tube are made visible by the light they reflect.

Figure 1.32, left, shows fluorescent cove lighting in the B. F. Goodrich Research Center Library.

Polarized Illumination

The detection of internal strains in such materials as glass, mounted lenses, lamp bulbs, radio tubes, transparent plastics, etc., may be facilitated by transmitted polarized light. The nonuniform spectral transmittance of strained areas causes the formation of color fringes which are visible to an inspector. With transparent models of structures and machine parts, it is possible to analyze strains under operating conditions.

Nonspecular Materials

Surface flaws, irregularities in surface shape, pit marks, scratches, and cracks in nonspecular or mat materials are most easily seen by lighting which strikes the surface obliquely in such a manner that nonuniform surface contours cast shadows. Wrinkles in roofing materials are revealed by small shadows which the wrinkles cast when the sheet is illuminated by a narrow light beam incident at a grazing angle.

Directional light also has been found useful for the inspection of sandpaper and Venetian blinds. The light may be specular for inspecting mat surfaces, but should be diffused at the source for examining polished or shiny materials.

Minute Details and High Precision

Careful inspection of very small objects may be greatly simplified by viewing their magnified images. For production work the magnified image may be projected on a screen. Because the projected silhouette is many times the actual size of the object, any irregular shapes or improper spacings can be detected readily. Similar devices are employed for the inspection of machine parts where accurate dimensions and contours are essential. One typical device now in common use projects an enlarged silhouette of the teeth of a gear on a profile chart. The meshing of these production gears with a perfectly cut standard is examined on the chart.

Color Control and Classification

Many manufacturing operations in the paint, lacquer, enamel, dye, textile, paper, tile, and printing fields include careful color-control procedures.

Moving Parts

It is sometimes necessary to inspect and study moving parts while they are operating. This can be done with stroboscopic illumination which can be adjusted to "stop" or "slow up" the motion of constant-speed rotating and reciprocating machinery. Stroboscopic lamps give flashes of light at controllable intervals (frequencies). Their flashing can be so timed that when the flash occurs, an object with rotating or reciprocating motion is always in exactly the same position and appears to stand still.

SECTION 2: ELECTRIC POWER

J. H. Eagen Hoffman & Crumpton, Architects, Pittsburgh, Pa.

There are many uses for electric power in the laboratories and shops comprising a research plant. Electric power is here distinguished from electric requirements for lighting the buildings.

Electric power is required for stationary equipment, portable equipment and specially built apparatus throughout the laboratory plant.

Stationary equipment includes such machinery as elevators, ventilating fans, refrigeration equipment, heating equipment, shop machinery and direct-current generators. Electric distribution and outlets for power to stationary equipment are ordinarily permanent and can be determined and arranged as to location and current characteristics when the buildings are in the planning stage.

Portable equipment includes such appliances as welding apparatus, portable tools, plug-in devices for testing, generating and regulating, etc. Specially built apparatus is that equipment made for a particular experiment. It is likely to be dismantled upon completion of the experiment.

Portable and specially built apparatus might be used for a relatively short period of time and then discontinued and replaced by other apparatus with entirely different electrical requirements. Consequently, flexibility of electric power facilities as to current characteristics and location of outlets is of primary importance throughout the laboratories and shops.

Office and library areas of the building require electric power for such purposes as business machines, book lifts, picture projectors and cleaning devices.

Most of this equipment will require alternating current although there are some instances where direct current will be needed. Direct current should be available in several common voltages throughout the laboratories and shops. It need not be distributed in as extensive an arrangement as alternating current for portable and specially built apparatus.

ELECTRIC SERVICE

Alternating current may be purchased from the local electric utility or it may be generated in the laboratory power plant. Both methods should be investigated by the design engineers in order to determine the one best suited to the laboratory plant economics and requirements. Energy for lighting would probably be obtained from the same source as the electric power.

Electric current purchased from a local utility company is generally supplied from high-tension lines. It is necessary to determine the total connected load for power and lighting and also the demand factor in order to arrive at the size of service facilities to be provided for the building. The demand factor is the ratio of the probable demand to the total connected load.

Primary service facilities, including high-tension service entrances, automatic or manual throw-overs, transformers and primary circuit breakers should be located either in underground vaults or in vaults especially built in the building. If the site permits, most of these facilities may be located outside the building on a fenced-in concrete platform built on the ground.

Secondary service facilities such as meters, switchgear, power-factor correction and voltage regulation should be readily accessible to authorized building employees and locked to all other persons. It is desirable that the room containing this equipment be as close as practical to the center of the load in order that feeder runs may be kept as short as possible and voltage drops at a minimum.

It will be well to investigate all the electric power rate schedules available from the utility company. Rates are generally subject to state government regulation and the company will recommend the rate that appears to be most favorable to the purchaser. Preliminary thinking about the operation of the plant may indicate a certain rate schedule as being advantageous. Actual use of the plant may show that the operation did not develop as planned, in which case a recheck should be made to determine if another of the available rate schedules would be more economical. Unless there is only one rate available, the purchaser should follow up the matter for sufficient time after starting operations to be certain the proper schedule is being used.

Some electric utility company rates contain penalty clauses for low power-factor conditions. In such cases the purchaser should determine if it is advantageous to pay the cost of power-factor correction equipment and realize a saving in the electric bills. Such equipment will usually be found to be a profitable investment.

Whether or not voltage regulation will be required will depend on conditions known to the utility company and on the requirements of the laboratory equipment. These questions should be studied by the design and utility company engineers.

Service feeders to loads throughout the building originate at the main switchboard. Circuit breakers to protect feeders are preferable to fuses as protective devices on switchboards since they require less space and provide momentary extra capacity for motor starting and can be reset manually. Undervoltage protection is available on some types of breakers.

ELECTRIC DISTRIBUTION

Electric-current distribution throughout the building may be accomplished by several systems now in common use.

The 4-wire 3-phase 120/208 volt distribution is often the most desirable. The more common wiring systems such as 3-wire 3-phase 220 volts and 3-wire single-phase 110/220 volts may be used if more suitable. If the power load is great, 3-wire 3-phase 440 volts may be used for the larger units.

In some laboratories such as in radiation laboratories and aviation research, special AC voltages or frequencies are needed. Transformers and frequency converters may be installed at the point of use to provide currents having the characteristics desired.

Service feeders should extend from the switchboard to each of the electric shafts in the building. The feeders may be run in conduits or wiring troughs, with pull boxes where required for ease and practicability in installation. The service feeders, either insulated copper conductors or copper busses in metal housing, are extended through the shafts. Extra conduits or raceways may be installed for future needs.

Sub-feeders protected by a fusible disconnect switch, cutout or circuit breaker may be connected to the shaft service feeders at each floor. These are connected to a distribution board for the floor area served by the shaft. Branches are run from the distribution board to laboratories for lighting, power outlets, stationary equipment and other service requirements.

Installation of branch circuit panelboards is wise in each room where central control is required. It is also a good plan to make switches on these panelboards easily accessible for control of lighting but to conceal switches for power circuits. In many cases it is important that power not be interrupted during an experiment. If power switches are installed as recommended, power cannot be interrupted by someone in search of a light switch.

Facilities for sub-metering may be provided at panelboards, feeder distribution boards and sub-feeders. If such facilities as current transformers, meters and cabinets are not immediately required, space should be provided for their future installation.

SPARE AND FUTURE CAPACITY

Consideration should be given to spare capacity and future load increases. If the past is a criterion, the electric load will grow as long as the operation of the building continues. Space should be allowed in the transformer room for possible increase in size of the transformers and in the switchboard room for additions to the switchgear.

Provision should be made for a number of spare conduits for future feeders in electric shafts, to distribution boards and to panelboards. Space for future branch circuits on panelboards should be considered, too.

RECEPTACLES, OUTLETS

Power receptacles should be polarized and identified as to the current to which they are connected. They may, where necessary, be vapor-proof, explosion-proof or dust-proof. Receptacles for AC should be selected for ease in identification and for positive polarity in connections. T-slotted receptacles should be provided for single-phase 115 volt outlets.

Outlets in walls in laboratories and shops may be in a gang arrangement in one box and include one or two of each kind of current outlet. Gang installations should be designed so that all attachment plugs may be inserted at one time.

Raceways for wiring for chemical benches and laboratory tables may be conduit and fittings or rectangular wireways of aluminum or steel with receptacles of different types arranged at regular intervals. On some laboratory equipment service aprons, with outlets recessed in the face of the apron and raceway concealed behind, are provided above the tabletop along the wall.

Raceways for floor outlets may be metal or fiber underfloor duct. Parallel ducts may be installed to keep certain electrical systems separate (telephones, signal and DC systems, for example). Underfloor duct outlet and junction box locations are established when the layout is being planned.

In some shops, owing to the necessity of changing the arrangement, size or quantity of equipment, it may be practical for current distribution to use feeder-bus and plug-in-bus. Feeder bus is an arrangement of copper bus bars run in a sheet metal enclosure and intended for use as a feeder only. Plug-in-bus is similar to feeder bus but is provided with plug-in type disconnect switches or circuit breakers for branch feeder take-offs.

EMERGENCY LIGHT POWER

A source of power for emergency lighting may be required in case of a power failure. State and municipal regulations often require emergency lighting under certain conditions, generally for places of assembly and of employment where occupancy after sundown is above allowable limits. Also, emergency lighting may be desirable at certain locations such as boiler rooms, concentrations of important equipment and, where necessary, for uninterrupted laboratory experiments.

The most common sources of power for emergency lighting are electric storage batteries, gas or steam driven generators, and auxiliary service lines with automatic throw-overs.

DIRECT CURRENT

Direct-current power, if not provided in all shops and laboratories, should be made available on the premises so that it can be furnished at locations where required either in a temporary or permanent manner. It is usually not necessary to provide as many DC outlets in each laboratory or shop as are provided for AC since the use of DC is not as extensive. The main requirement is that it be available in a number of locations and in suitable capacities and that it can be extended to other locations if necessary.

Except in rare cases, the utility companies do not provide DC service and it is unlikely that it will be available commercially for any newly planned building. It will therefore usually be necessary for the laboratory to provide its own source of DC.

Direct current electric power can be provided by:

A. Storage batteries
B. Motor-generator sets
C. Rectifiers
D. Synchronous convertors.

A. Provision of DC for electric power by storage batteries is satisfactory in laboratories where relatively small currents at practically non-fluctuating voltages are required. Batteries give a good steady flow of current which can be well regulated.

Storage batteries are not recommended as the main source of DC for general distribution throughout the building. Usually the size and space requirements are too great to be economical and voltage-drop conditions would likely be unfavorable.

The electric storage battery is extremely portable and may be moved to the point required. When the service is completed the batteries may be returned to the central storage room for charging.

With reasonably good maintenance batteries may have a service life of from ten to twenty years. A storage battery requires no more frequent attention than proper charging and the addition of water about four times per year.

B. Motor-generator sets to convert AC to DC are available in sizes of 1 kw to 10,000 kw. Current from these may be used for general distribution to supply units or devices not requiring highly accurate voltage regulation. Constant voltages may be provided by the use of regulators. Equipment of several sizes may be placed in the generating plant so that the smaller units can be used when the load is light and the larger when the load is heavy.

C. A more recent development for conversion of AC to DC is the metal-tube rectifier. These are economically suitable for loads of from 40 kw to 1000 kw at voltages from 125 to 600. They are considered particularly suitable for laboratory work and are more efficient and less costly to maintain than motor generator sets. A small sealed-tube type rectifier for certain voltages may be used in place of a storage battery.

D. Synchronous converters are not often used at present but may be competitive in larger sizes.

Conversion equipment, including the main DC switchboard, should be placed in a fire-resistant room near the load center. Local building code regulations may control the construction and ventilation of rooms housing electric storage batteries. The main switchboard should be sectionalized with a main circuit breaker, throw-over switch, ammeter and voltmeter for each source of supply. Space should be left on the main switchboard for future circuits.

Direct current may be distributed in the manner described for AC, which comprises an extensive system of feeders, distribution boards, panelboards and other supply facilities. The first cost of this type of system is rather high considering the probable infrequent use and limited load in most laboratories. The plugboard type of current distribution, such as is furnished by the Standard Electric Time Company, provides an economical and flexible method which meets the requirements in most instances. This system may also be used for the distribution of other types of special currents where necessary.

The plug-board system includes a main switchboard located at the source of supply of special currents which, as has been stated, may be motor generator sets, batteries, or other types of generators. This switchboard should be provided with circuit breakers of various capacities, one of which may be included in any circuit which is to be set up. The main switchboard has receptacles or bushings connected to the source of supply, into which plugs attached to flexible cords may be inserted. Also located on this board are bushings attached to feeders leading to smaller plugboards at each floor in each shaft. The bushings may have colored plastic rims for identification purposes. Flexible cords should be heavy and durable with the proper plugs securely attached. The plugs may also be had in various colors to correspond with the bushings into which they are to be inserted.

Circuits to plugboards on each floor, in the shafts, are connected to polarized receptacles in the laboratories. If only one circuit from the main plugboard is run to each shaft-board, it may be advisable to provide jumpers to the floors above and below so that circuits for different types of current may be available at any specific location.

Electrical engineering for light and power requirements for a laboratory building involves a great deal of study and application of sound experience to secure practical and economical results. A consulting engineer should be employed when the project is in the preliminary planning stage.

6

LABORATORY VENTILATION

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The function of ventilation is to maintain a low concentration of atmospheric impurities that may be generated within the space, or to prevent build-up of immoderate temperatures. The contaminants in rooms where people congregate are body odors, body heat, water vapor, and tobacco smoke. In laboratories, the contaminants of concern are chemical substances, vapors, fumes, dust, or heat from experimental equipment and solar radiation.

There are basically two mechanisms whereby ventilation accomplishes the desired end. One is a simple process of dilution (commonly called *general ventilation*). If one knew that a metallic fume were being volatilized at a rate of 10 milligrams/minute, and he wishes to maintain average concentrations in the space below 1 milligram/cubic meter (1 mg./35 cubic feet), then, obviously, a ventilation rate of 350 cubic feet/minute would be required to meet this specification. This line of reasoning is the basis of design for many problems of industrial ventilation. However, it is clearly not applicable to laboratory ventilation design on a quantitative basis because of the impossibility of anticipating the character and quantity of air contaminants.

The other ventilation mechanism is known as local exhaust, wherein the contaminant is withdrawn at its point of origin by an air exhaust system for discharge to the exterior of the building. The enclosed hood used in laboratories operates by such a mechanism.

Some may wish to include a third mechanism—air motion—whose magnitude is described by the air velocity. This, however, has reference only to human comfort in relation to the thermal environment. Air motion accelerates the evaporation of sweat, the cooling effect of which is beneficial to comfort when temperatures are otherwise above the comfort level. Air motion, as such, has no ventilation significance in laboratory spaces in the control of air purity.

Specifications based on a number of cubic feet of air per minute divided by the room volume, i.e., number of room volume air changes are meaningless, though a popular method of describing ventilating rates. A* simple statement of the flow rate per room in cubic feet per minute describes the ventilation rate properly and adequately. Rate of air change in terms of room volume is a way, merely, of describing the rate of die-away of the concentration that may have been generated by a single release of vapor, by accident for example. In this sense, therefore, it is a specification for ventilation clearance following accidents, the necessary description of which (quantity and safe concentration) are always lacking. Some maintain that the rate of air change in relation to room volume describes the average velocity of air motion and is therefore significant from the standpoint of thermal comfort to the occupants. This, however, has little foundation. It is not practical to provide an air supply from a central fan at a high enough rate to create significant air velocities in a room. Air circulating fans serve this function effectively and economically.

The practical basis for ventilation of laboratories is in the provision of adequate hoods. The air supplied to the laboratory spaces to replace the air exhausted through the hoods serves two functions. It dilutes fumes and vapors from miscellaneous sources in the laboratory outside the hood, and, on entering the hood opening serves to prevent the escape of any fumes or the like generated in the hood interior. Thus, both ventilation mechanisms, local exhaust and dilution, operate simultaneously when air is exhausted through the hood.

The ventilation design basis for laboratories may be summarized in the rule: *provide hood facilities adequate to prevent the escape of potential air contaminants, and expect the laboratory worker to arrange his operations relative thereto so that the dilution capacity of the general ventilation will never be exceeded.*

In the ventilation of laboratories where heat is generated by motors, miscellaneous mechanical equipment or furnaces, calculations can readily be made of the rate of air flow required to limit the average temperature rise to some moderate increment, e.g., 5°F. This will provide a concept of the magnitude of the ventilation problem. "Dilution of the heat units" by general ventilation, combined with air circulating fans for increase of air velocity can create a bearable environment if the required ventilation rate is within practical limits. This treatment, however, is seldom satisfactory where heat generation is large; a space that is only a few degrees above that of an adjoining room is intensely disagreeable in warm weather.

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* Hemeon, W.C.L. "Air Dilution in Industrial Ventilation". Heating & Ventilating, March, 1941, pp. 71-74.

Fundamental improvements can be effected by a. suppression of radiant heat by shielding, b. insulation of hot surfaces, and c. enclosure of heat sources and exhausting the enclosure. All these involve shielding, the importance of which cannot be exaggerated.

HOOD VENTILATION

The essence of the problem of laboratory hood design is in the selection of rates of ventilation through them which will effectively prevent escape of noxious fumes and gases without excessive air flow, for the greater the air flow the greater the cost of heating the supply air. This question has received additional attention in recent years with the increasing interest in air conditioning, since the cost of the latter is proportional to the increase, beyond a point, in air flow. The cost of conditioning air, moreover, is many times greater than heating the same volume in the heating season.

The rate at which air is drawn through the open face of a hood fixes the velocity and the latter must be sufficient not only to overcome thermal effects originating inside the hood (see discussion below) but, also, air disturbances outside the hood which may have a tendency to cause outward spillage of the contaminated air from the hood interior. Outside air disturbances may result from the body motion of laboratory workers, drafts from open windows, or by air circulation at the hood opening resulting from improper type and location of supply air grilles. The last two are factors of major importance. Hood location relative to windows is therefore clearly important in laboratories that are not air conditioned; open in summer-time for comfort, the air disturbances thereby created may interfere seriously with the air currents flowing into the hood opening.

It has been common practice to fix the rate of hood exhaust so as to realize an average linear air velocity through the area of the working opening at the front, of 50 to 60 feet/minute; that is 50 to 60 cubic feet/minute/square foot of hood face area. There are, however, many situations where velocities of 50 feet/minute or less are entirely adequate, and others where velocities as high as 75 feet/minute are inadequate.

Thermal Effects

The different situations affecting hood performance in preventing escape of contaminants generated within, are related principally to the rate of heat release by burners, hot plates and other heat-producing equipment. Upward moving thermal air currents are generated within the hood at flow rates that increase with increasing use of heat. If the hood fan capacity is less than the upward flow of the hot, contaminated air currents, then interior air will flow outward just under the top edge of the hood face, even while air enters through lower sections. The same thing will occur even with a

Figure 1.33 shows the spillage of fumes from hoods in conditions of high heat release on the interior: (a) insufficient exhaust capacity, though proper location of exhaust outlet, (b) sufficient exhaust capacity, but improper exhaust location, and (c) same exhaust capacity as (b), properly located at top.

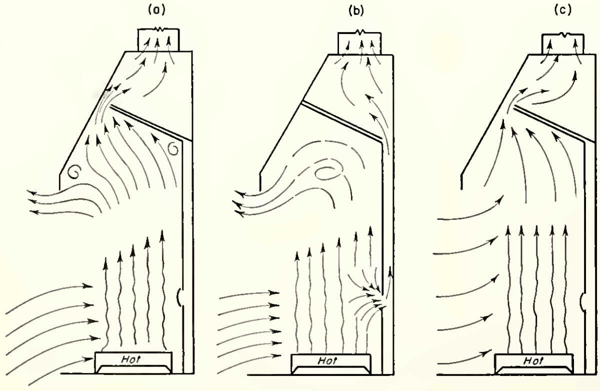
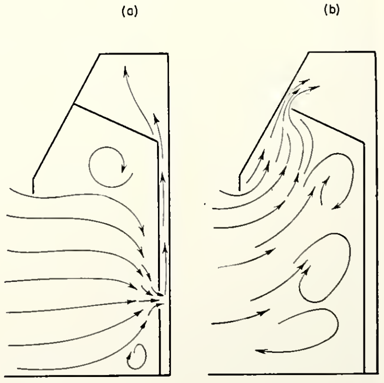


Figure 1.34 Diagram (a) shows how air flow distribution at the face of hood with exhaust through a low slot and through upper part of hood prevents heat generation in the hood. With the exhaust at top, as in (b), the relatively lean flow causes poor distribution near the bench.



sufficient rate of hood exhaust if the exhaust connection is below the upper rim of the hood opening (see figure I.33).

The generation of heat within a hood has an additional effect of importance in certain cases. The existence of a volume of hot air in the space above the hood face opening results in a thermostatic pressure against all surrounding surfaces. If there are any cracks or holes in this portion of the hood casing, leakage of contaminated air outward may occur in spite of the operation of the exhaust system. This may be significant where the contaminant is either highly malodorous or highly toxic. Whether it occurs at all is dependent on the relationship between rate of heat generation, linear velocity into the hood, height of hood space from the upper rim of the hood opening to the point of potential leakage, and the existence of appreciable crack or hole area.

Prevention of Thermal Spillage

Leakage resulting from thermostatic pressure may be prevented by ensuring that there are no cracks or other openings in the upper portions of the shell casing. Hoods provided by laboratory furniture makers are well constructed in this respect. Home-made hoods frequently leak by this mechanism. The spillage at the upper rim of the hood opening that may occur in conditions of high rate of heat generation is prevented by: a. exhausting from the upper space above the hood opening, and b. in providing a sufficient rate of hood exhaust in relation to the area of the hood opening. A hood with moderate exhaust, properly connected at the top of the hood, in which thermal air spillage occurs may be made to perform satisfactorily by partial closure of the face opening at the top. In hoods with sash front, this is accomplished by merely lowering the window partially.

Other Factors Affecting Efficiency

The majority of operations carried on in hoods produce only small amounts of fume, most of which are non-toxic. In many cases the amounts volatilized are so small that mere dilution with the fresh air entering the hood reduces their concentration in the air within the hood to acceptable levels, so that if, due to low hood efficiency, some of this mildly contaminated air escaped from the hood interior instead of passing into the exhaust flue with the main air stream, it would not be noticed.

This illustrates, further, the wide variation in hood performance that may be noted due to variation in type of hood operations. It also illustrates the pitfalls that are likely to be encountered in any casual investigation of hood efficiencies based on obtaining opinions of a few laboratory workers, or observations of hood performance without regard for the type, amount, and circumstances of fume evolution.

Location of Exhaust Connections

The question of locating the exhaust connection was discussed above for the case where large amounts of heat cause buoyant streams of hot air to flow upward. Contrary to common opinion, there are rarely any opposite density effects resulting in strong downward flow of gases. It can be shown that the density of a vapor having a high molecular weight relative to air is not the ratio of those molecular weights, because the vapor is usually mixed with air and the degree of dilution with air determines, therefore, the relative density of contaminated air and surrounding air. A mixture of 1% gas or vapor and 99% air would, in general, be unusually rich; even *its* density, however, would be only a little greater than unity. The occasional exceptions will be obvious, e.g., rapidly evaporating carbon dioxide ice. It is therefore false to conceive of vapors and gases as being lighter than air or heavier than air, at least in so far as ventilation of spaces is concerned.

Exhaust slots near or just above bench level do contribute beneficially, however, to hood ventilation for reasons different from those related to density of escaping gases. Gases or fumes are withdrawn directly from their point of origin toward a slot exhaust as illustrated in figure I.34. A goodly proportion of the fumes in the example are diverted directly at distances close to the backplate. Those not channeled in this manner would still be prevented from escaping by the stream of air flowing inward through the front opening.

The low exhaust slot has the further advantage of providing more uniform velocities through the front opening. With no heat release within the hood, and exhaust only from the upper part of the enclosure, velocities through the face opening are greater near the upper rim than near bench level and may be inadequate in situations where the contaminant is released at bench level near the front of the hood.

A combination arrangement with damper control permits the laboratory worker to select either exhaust from the top space or from a slot at the rear wall near bench level (see figure I.35).

Rate of Hood Ventilation

In laboratory buildings having a large number of hoods, the most economical yet effective rate of hood exhaust is a question of some importance because of the cost of heating the make-up air in winter. There is an extreme variation in ventilation needs between different laboratories at the same time, and the same laboratory at different times. A given laboratory building may, for example, actually require at some given hour only 10-15% of the installed exhaust capacity considering the hood use in the building as a whole. The actual need in this hypothetical example is shifting between different laboratories from hour to hour and from day to day and, since the hood fans are not always shut off during periods of non-use, the entire capacity must be provided. These considerations render even more

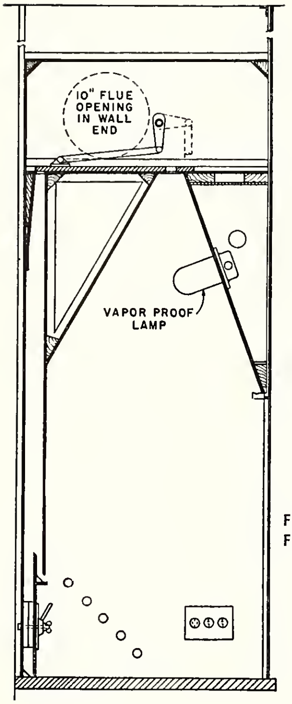


Figure 1.35
Fume hood.

pointed the question as to how liberal a capacity to provide for each hood.

It has been stated previously that a common average face velocity value employed for specifying hood ventilation rates is 50 to 60 feet/minute. Laboratory furniture makers consider the following figures advisable:

High school laboratories—50-60 feet/minute
Colleges and hospitals—60-80 feet/minute
Industrial—80-100 feet/minute.

Hoover,* in 1930, discussed the matter as follows, and his remarks should be considered in conjunction with the discussion, above, on "Thermal Effects" and "Other Factors Affecting Efficiency:"

> Whatever the method of moving the air from the hood structure, there is general agreement upon the velocities which should be maintained through the openings in the front of the hood. If the hood structure is properly designed, with continuous inlet slots at top and bottom of back of hood, and strong air currents from without the hood be avoided, it is possible to prevent the escape of objectionable vapors and gases from the open type of hood, ten feet or less in length, by a velocity of from 35 to 50 linear feet/minute across the entire hood opening. Under certain conditions, somewhat wider variations in the velocity may be employed. For laboratories in which the least objectionable type of work is carried on, a velocity of from 25 to 30 feet/minute across the opening is sufficient, and the maximum that is required for the handling of very dangerous vapors is usually considered to be from 50 to 60 feet/minute. The total amount of air that is withdrawn from the hood for each worker consequently depends upon the size of the opening in the hood, and this, of course, will be true whether open or partly closed hoods are used.

We venture the opinion that a hood face velocity of 50 feet/minute would provide adequate fume control for 85% to 90% of the hood operations in an average group of laboratories; a velocity of 75 feet/minute for 95% or more; and a velocity of 100 feet/minute for nearly 100%.

Hoods should prevent fume escape nearly 100% of the time, yet doubling the exhaust capacity, over 50 feet/minute, is a heavy price to pay for control of the final increment.

It is clear from the foregoing reasoning that the most economical hood arrangement is one based on a face velocity of 50 feet/minute with a closure device permitting the laboratory worker to deduce the area of the working opening at the front. The window-sash-front hood is an example of one type with this facility. They are commonly arranged for complete closure of the front opening, but a half-window sash in which the closed position covered only 50% of the total opening would increase the velocity to 100 feet/minute and be satisfactory for most situations. The disadvantages of sash front hoods are well summed up by Hoover: *

> It cannot be denied that fumes can be removed with the greatest economy of ventilation by placing them in a space which is entirely separate from the one in which the worker is located. [But] there are but few substances which are so dangerous as to call for such complete removal from the neighborhood of the worker; moreover the primary object of a hood is to enable the worker to carry on with ease and comfort a given reaction while at the same time observing and controlling its progress. With nine-tenths of the reactions carried out in a chemical laboratory, evolving objectionable fumes, this can undoubtedly be best done in an open hood . . . . the expense and difficulty of maintaining windows, sliding panels, or other hood-closing devices in a corrosive atmosphere is so great that it is generally simpler and cheaper to remove a somewhat larger body of air from the hood, do away with all closing devices or windows, and thus enable the worker to have ready access to the apparatus that is being used in the hood. This general conclusion seems in accord with the practice of the best modern laboratories, as it can be observed that an increased use of open hoods is being made. Improved design of hoods and proper location of exhaust openings contribute, of course, to the increased use of open hoods . . . While with properly designed hoods it is the experience of several laboratories that such devices [closures] are unnecessary for the small number of reactions evolving substances very dangerous even in small concentrations, some chemists may wish to have available special removable screens or shutters of glass or other non-combustible material.

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* C. R. Hoover, "Hood Ventilation," Laboratory Construction and Equipment, New York: The Chemical Foundation, 1930, pp. 74-76.

The disadvantages of sash-front hoods set forth in the foregoing quotation are undeniable. However, they are practically imperative where the laboratories are to be air conditioned, as will be shown in the discussion below.

HOODS FOR AIR CONDITIONING

Summer air conditioning of laboratory buildings in the conventional arrangement requires refrigerating capacity not only to compensate for heat gain through walls of the building but also sufficient for a flow of supply air equivalent to that exhausted by all hoods in the building. This has stimulated attempts to design hoods incorporating arrangements for supplying make-up air directly to the hood to avoid the need for conditioning the latter.

A complete appraisal of the efficiency of these arrangements is not possible at this writing, because of the variety of hood operations that are encountered, each of which demands different degrees of hood performance, coupled with the difficulty in appraising the reports of the laboratory workers who use them. No systematic studies have been made for publication. The vapors from certain laboratory operations may be satisfactorily controlled in a hood which directly exhausted only 85% of them, whereas that degree of control would be utterly inadequate for other fumes. Or, for some operations a hood may prevent escape of any contaminants but allow escape of excessive amounts with other operations, notably those involving high heat generation.

Behavior of Peripheral Supply Streams

A hypothetical scheme, illustrated in figure I.36, delivers streams of unconditioned air through grilled slots across the face of the hood. The grilles are disposed vertically at each side of the opening to discharge the air streams horizontally across the face, and at an inward angle. The following analysis of such a scheme is intended to emphasize the complications of resulting air flow patterns and to show the need for close examination of novel hood designs.

Any free air stream like that issuing from these lateral slots does not retain its original identity of shape and flow rate due to the turbulent mixing with surrounding air which takes place. Thus, if a hood is exhausted at a rate of 900 cubic feet/minute, one could not successfully supply the same flow through side grilles, because the supply air stream would set in motion surrounding air masses and become mixed with them. To exhaust the complete flow of supply air, therefore, would require an exhaust capacity greater than it by the amount of entrainment of surrounding air. The air entrained would be composed partly of conditioned room air.

If one half of the hood width, i.e., the maximum travel of each supply air stream, is not greater than about five times the grilled slot width, then the entrainment would not be expected to exceed about one fourth to one third of the supply air flow rate; half of this would be supplied by the boundary on the room-side, and would thus entrain conditioned air from the room.

In the turbulent mixing process, the air stream in-

Figure I.36 illustrates complications in analysis of a hypothetical scheme for supply unconditioned air at front edge of a hood in an air conditioned room.

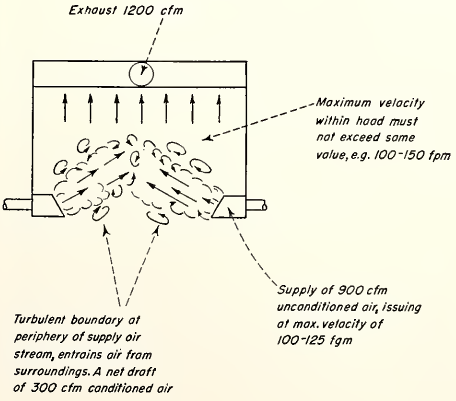
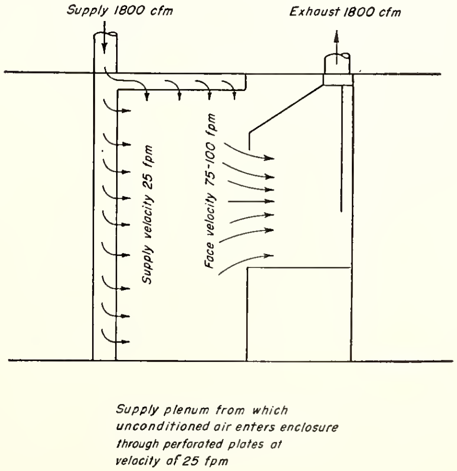

Exhaust 1200 cfm
Maximum velocity within hood must not exceed some value, e.g. 100-150 fpm
Supply of 900 cfm unconditioned air, issuing at max. velocity of 100-125 fgm
Turbulent boundary at periphery of supply air stream, entrains air from surroundings. A net draft of 300 cfm conditioned air

Figure I.37 is a diagrammatic illustration of a hypothetical hood arrangement for an air conditioned laboratory which would use no conditioned air.


Supply 1800 cfm
Exhaust 1800 cfm
Supply velocity 25 fpm
Face velocity 75-100 fpm
Supply plenum from which unconditioned air enters enclosure through perforated plates at velocity of 25 fpm

creases in diameter with distance. The included angle of the air stream is 20° to 30°, so the supply air stream issuing from side slots would have to be directed inwardly at some angle greater than 10° to 15° to ensure a positive inward direction to its outermost boundaries. This would limit the length of hood, i.e., the distance between supply slots.

The maximum velocity in the air stream within the hood (again where the maximum stream travel is not greater than five times the slot width) may be no more than 10% to 20% greater than the velocity of issue from the supply slot. (If the latter is covered by a grille the *gross* area is used with the flow rate to calculate the velocity of issue.) Since velocities within the hood should not be greater than about 150 feet/minute (possibly less) it is clear that velocities of issue should not exceed 100-125 feet/minute.

The above analysis does not constitute a presentation of a feasible arrangement. Rather, it is intended to illustrate the pitfalls that need to be avoided in consideration of a superficially plausible design of novel character. The figures employed in the analysis are approximately correct but not sufficiently accurate to permit final design conclusions.

Enclosed Hood

Another hypothetical arrangement which will serve further to illustrate some of the facts and problems related to conservation of conditioned air is illustrated in figure I.37. As in the previous discussion, the arrangement is not presented as a recommended hood. Rather, it is intended to illustrate some principles of air flow and to stimulate thought. The arrangement illustrated does not consider the important physical aspects of convenience to laboratory workers. Indeed, as pictured, it would be completely unacceptable to most laboratory workers.

It shows a hood completely enclosed in a cubicle to which outside, unconditioned air is supplied at a rate equivalent to that being exhausted. A point of major importance is in the provision for very low velocity in the air stream entering the hood, and in its discharge into the space at points both above and below the level of the hood opening. In this way, the air entering the hood does so in a normal manner without turbulence—in contrast to an arrangement where the air would be discharged at high velocity through a panel directly opposite the hood opening. In the latter case, impingement of the supply air stream on the air within the hood would seriously interfere with normal hood operation and would actually blow some of the interior contaminated air out of the hood.

Excellent hood performance would be attained in such a design with no consumption of conditioned air. One other shortcoming in this arrangement, besides the problem of use convenience, should be noted. The laboratory proper requires some positive ventilation which in conventional hoods is provided by the air that is permitted to pass out of the room through the hood. The same requirement applies here, but is not provided for in the scheme shown.

Sash-Front Hoods with Integral Air Supply

It has been indicated previously that hoods with provision for reducing the area of front opening are the most economical from the standpoint of ventilation. This is an even more important consideration in air-conditioned laboratories.

Fume hoods of novel type have been designed and installed just prior to this writing whose objective is to reduce the required rate of exhaust from the room. From the standpoint of hood ventilation the mechanism is as follows (see figure I.38). Air is drawn through the face of the hood at a face velocity of about 30 feet/minute. Fumes pass directly through adjustable slots in a baffle plate, which constitutes the rear wall of the hood, due to the negative pressure in the space behind the slotted baffle plate. The essential difference between this arrangement and one described previously in figure I.33 is in the several adjustable slots and in the method of creating the negative pressure provided in the new design. The negative pressure is created by the action of a venturi nozzle behind and at the bottom of the space behind the baffle plate, through which unconditioned air passes upward at high velocity. The exhaust fan has a capacity to handle this volume of ejector air plus the volume of conditioned air entering the front opening at 30-35 feet/minute.

This method of drawing air through back plate slots may have the advantage of somewhat greater simplicity in the initial distribution and adjustment to flow within the hood, although this is not completely obvious. It would be mechanically possible to effect the same result with an exhaust fan alone by initial adjustment and locking of restrictions at the junction of the space behind the plate and the slot at the top which communicates with the main hood.

Another feature which is regarded by the designers as of primary significance is a baffle arrangement which forces some of the primary jet air flowing behind the back plate to spill outward through orifices into the main space of the hood interior. This air creates turbulence and a mixing action in the upper portion of the interior space and is eventually exhausted along with the main portion of air entering the hood front. The effect of this turbulent air pattern is solely one of mixing. It cannot affect performance of the hood, insofar as helping prevent escape of air contaminants is concerned.

The most important aspect of this design, and one which ensures effective control of air contaminants, is the inclusion of a sash-front which permits the front opening to be reduced by lowering the window to its bottom limit, which is 3 inches from the bench top. There are many hood operations that would permit the escape of fumes into the room unless the sash were lowered.

Hoods which are to have face velocities lower than 50-60 feet minute should never be designed without sash fronts or other closures permitting the worker to reduce the frontal area.

METHOD OF EVALUATING UNTRIED DESIGNS

An attempt has been made in the preceding discussions to show how known principles of air flow can be applied to an analysis of different hood arrangements. Their accuracy, however, is low in relation to information required in design of hoods for air-conditioned spaces. Uncertainties of 50% to 75% in exhaust requirements of a hood are possible in the present state of knowledge of air flow patterns. In industrial ventilation, safety factors of this magnitude are usually permissible, but in an air conditioned space, a reduction in hood exhaust rate of these amounts would represent major economies.

There is, therefore, need for a test procedure whereby new and radical hood designs can be demonstrated either to have merit or to be without value. The cost of a model test would be small in relation to the valuable information that would be obtained thereby.

The elements of such a test are simple. A tell-tale smoke or odor is generated in the interior at the rear, sides and front of the hood-enclosed bench undergoing test and observations made on *the degree to which air escapes*, in various circumstances *from the interior*.

Test conditions should include some in which there are at least two rates of heat evolution. For the lower rate, Meker burners can be used, in some suitable number, e.g., one burner for each foot of hood width, etc. For the higher heat use rate, one or more gas-burner hot plates would be suitable, and may be supplemented by Meker burners if the size of the test-hood appears to warrant it. Copious volumes of visible smoke may be generated within the hood as by an ammonia-HCl mixing device. (Stannous chloride or titanium tetrachloride is unsuitable in heated atmospheres.) A quantity of malodorous vapor may also be evaporated (mercaptans are suitable) either simultaneously or separately, and escape of interior air discovered by noting the presence of odor in the room air. The odor test is much more sensitive than the smoke test and is therefore valuable as a supplement to the latter.

Such a test procedure can serve as the basis of specifications for hood performance.

CHEMICAL ENGINEERING OR PILOT PLANT LABORATORIES

The ventilation requirements of chemical engineering laboratories are as variable as those of industrial operations in general and cannot be predicted. The practice of estimating probable ventilation requirements on an arbitrary basis of changing the room volume at some stipulated rate is an illusory estimate. Local exhaust hoods are required for proper control of the miscellaneous contaminants that might be generated, and their requirements depend on a number of factors that cannot be described in a general rule.

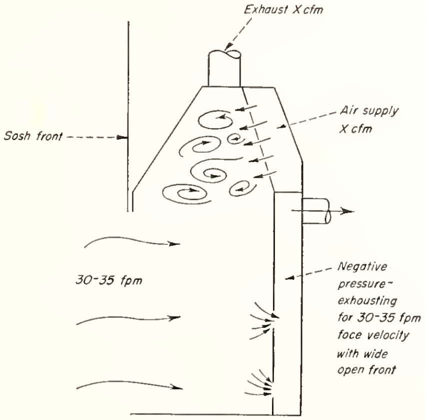

Exhaust X cfm
Air supply X cfm
Sash front
30-35 fpm
Negative pressure-exhausting for 30-35 fpm face velocity with wide open front

Figure 1.38 is a diagrammatic representation of one hood arrangement that has been used. In actual hood, negative pressure behind baffle plate and air supply for agitation are effected by a single source of unconditioned air under pressure.

Where a preliminary estimate must be made, for design of heating plant, the following is a practical rule: an exhaust capacity may be required equivalent to 500-1000 cubic feet/minute/unit of equipment except furnaces and other high temperature processes; and 1000-1500 cubic feet/minute/furnace or similar equipment. Obviously, this rule is highly approximate.

Canopy Hoods

Canopy hoods where there is a free space from the floor to bottom rim of the canopy hood of 5-6 feet are indicated for control of fumes from furnaces or the like because such equipment creates buoyant streams of hot air which travel upward naturally into the hood structure. For room temperature processes, however, they are generally useless with the rates of air flow commonly provided. Their mis-application in this manner is wide-spread and it is, therefore, desired to emphasize the point that high canopy hoods above room-temperature processes should never be relied upon for control of fumes, dust, and the like.

The proper method, instead, is to locate small exhaust openings close to the several actual sources of contaminant around the equipment, to withdraw the contaminated air at the sources, usually laterally, directly into a duct system before it can mix with room air. Partial enclosures around such sources are even more effective. Reference should be made in actual problems to engineers accustomed to the design of local exhaust systems and ventilation for industrial processes.

CONCLUSION

The reader will have understood from the foregoing discussion that the aspects of ventilation peculiar to laboratory buildings center around the fume hood. Other problems of ventilation design—the need for an air supply system, duct work layout, fan selection, and so forth—are common to all buildings and the best engineering advice should be obtained for their solution. This advice is especially important where the building is to be air conditioned. For those desirous of exploring some of these details further, a comprehensive bibliography is appended to this chapter.

It is a matter of common experience that air conditioning results in greatly improved worker efficiency in periods of hot weather and is regarded by many people as an essential element in a new building. It should hardly be necessary to point out that supply air systems are required having total fan capacity equivalent to the exhaust capacity of all hoods in the building.

7

SAFETY PRECAUTIONS

F. A. Van Atta

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There are certain problems in the design of laboratories, irrespective of the specific use to which they are to be put, which must be satisfactorily solved if their facilities are to be used safely and efficiently. It is fundamental that the primary structure be strong enough for the purpose. Many types of laboratory installations impose very heavy concentrated floor loads on the building in which they are held. When equipment or processes requiring such heavy installations are to be used, proper pre-planning will locate them where the installations will involve the least possible special construction and consequently will involve the least hazard of damage to the structure.

Safe and sufficient means of ingress and egress from the laboratory under both ordinary and emergency conditions must be provided. According to the recommendations of the National Fire Protection Association[*] at least two means of egress from each floor are required. These exits must be located as far apart as possible and on opposite sides of the building. The total number of exits required depends on the size of the establishment and on the kind of operations carried on. For jobs with relatively high fire hazards no portion of the building should be more than 75 feet from the nearest exit. For low hazard occupancy this distance may be increased to as much as 150 feet.

Outside stairways or fire escapes are of little value as means of egress in a fire emergency and should not be depended upon. In several states they are not considered in calculating the required means of egress. Exits from the upper floors should be through smokeproof enclosed stairways and through enclosed elevator shafts.

In planning such installations, municipal and state building codes should be consulted and those having responsibility for their enforcement should be interviewed if there is any question of interpretation.

Safe access to all parts of the laboratory building should be provided by wide passageways and by proper stairs and ramps for going from one level to another.[†] In the many situations where it is necessary to have openings two or more stories high to accommodate large apparatus, it will be possible to do most of the work at elevation from fixed platforms with standard guard rails and toeboards.[‡] The platforms will be connected by standard stairways if the installation has been carefully planned. As a specific example, if a crane is installed in such a structure a walkway should be provided at the end of the crane runway both for maintenance of the crane bridge and for access to the cab. By the same type of reasoning, fixed platforms should be provided on other types of high equipment wherever there are instruments to be read or where there will be repetitive maintenance work to be carried on.

The provision of safe means of access to all parts of the establishment and of safe and adequate means of egress for all occupants is particularly pressing for educational laboratories where the occupancy of the laboratory is apt to be much more intensive than in good industrial practice.

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[*] Building Exits Code A 9.1—1942, American Standards Association, 70 East 45th Street, New York, N. Y.

[†] Stairs and Ramps, Safe Practices Pamphlet No. 2, National Society Council, Chicago.

[‡] Floor and Wall Openings, Railings and Toe Boards, American Standards Association Standard No. A12—1932, American Standards Association, 70 East 45th Street, New York 17, N. Y.

Closely related to the question of safe ingress and egress to the plant and safe access to all parts, is the necessity for proper facilities for the receiving and storage of the various materials handled in the course of the operations. This is probably more pressing in a chemical laboratory than in most of the physical and engineering laboratories. Even in a strength of materials laboratory, however, provisions should be made for receiving and storing specimens while they are waiting to be made up into the various test forms and also for storage of the tested samples until final disposition is made of them.

STORAGE

A chemical laboratory, whether educational, industrial control, research, or chemical engineering cannot avoid a rather considerable problem of storage of hazardous materials. It is almost always necessary to keep on hand flammable materials and toxics. Compressed gases in considerable quantities and some explosive materials are also often required. It is usually necessary to make provision for a central storage depot for main supplies of these materials and also for storage in the laboratory proper of small amounts for immediate use. The central storage area is often cut up into a number of types of storage facilities for the different types of material to be handled. Separate areas for flammable liquids, compressed gases, cold storage, samples and general chemical storage should be provided.

The main supply of flammable liquids should be isolated from the rest of the structure. The preferable means of isolation is in a detached building used for no other purpose. If such a building is located so as to seriously expose any other structures to fire the storage building should be of good fire resistive construction. Walls, floors, and ceilings should be not less than 4 inches of reinforced concrete or 8 inches of brick or concrete fire tile set in Portland cement mortar and plastered on both sides with Portland cement plaster. The wall openings should be protected by standard fire doors.

The floor should be water-proofed and drained to a safe place where water can be separated from any organic liquid. The door sills should be raised so that water and liquid will go down the drain in case of emergency.

Drum racks should be provided with metal drip pans beneath the racks for open drums from which the liquid is to be drawn. Drum racks and shelving should be of non-combustible construction.

Ventilation should preferably be by natural draft with intakes close to the floor level and make-up air admitted close to the ceiling. One of the best methods of ventilation for an out-door storage house, where it can be done without dangerously exposing other buildings, is the opening of the lower part of the walls, to a height of 18 or 24 inches with a 6-inch curb around the floor. This is done in the California-type pump houses largely used in the oil industry. If this type of construction would seriously expose surrounding structures, the storage building should be ventilated by means of roof openings with ducts extended to within 6 to 8 inches of the floor. Natural ventilation is always more desirable than mechanical if natural gravity ventilation can be made to work. Its real advantage is that it operates continuously without attention.

If artificial light is required in the storage building the electrical installation should be in accordance with the requirements for Group 1, Class C or Class D exposures of Article 500 of the National Electric Code according to the nature of the storage.

If a considerable number of unopened drums are to be stored it is perfectly satisfactory to place them on racks under a shed which will protect them from direct sun and from rain and snow, provided that they are set well away from buildings. They should not be left on loading docks nor stored in narrow passageways between buildings.

If it is necessary to store flammable solvents inside the building, they should be in a room above grade rather than in the basement or other places where there is not a good chance for ventilation to remove any vapor which is released. If there is any great quantity of flammable solvent to be in storage the storage room should not be close to openings to the basement or to lower floors where there are open sources of ignition.

The construction of the storage room should be the same as that provided for the outside storage building. In addition it should have an automatic system of fire extinguishment, either automatic fixed fire extinguishers suitable for Class B fires or automatic sprinklers. First aid extinguishers suitable for Class B fires should also be provided.

Ample provision should be made for storage of general chemicals so that they can be handled without undue congestion. The area should have a floor treated to make it impervious to the action of spilled corrosives and should be well drained to facilitate cleaning.

Boxed carboys should be segregated according to the kind of material and should never be stored in stacks more than three carboys high. The strongest oxidizing agents should not be stacked higher than two tiers. The aisles should be wide enough to permit handling the carboys in and out of the tiers with a special carboy truck without the necessity of moving them by hand.

The plan for storage of materials should be carefully worked out so that substances which are apt to react violently will be separated by considerable distances. While such separation will not prevent breakage it can minimize the damage if extensive breakage should occur.

Provision should be made for storage of compressed gas cylinders in a place where they will not be exposed to excessively high temperatures or to direct sunlight.

Racks should be provided for both full and empty cylinders so that they will be firmly supported in a vertical position with the valves protected from mechanical injuries.

The shelves provided for liquid materials and solutions in glass should have raised edges and be lined with an inert material so that the reagent will be retained in the shelf in case of breakage of a bottle.

This same arrangement of shelving is desirable for materials stored in glass in the working areas. It is rarely either necessary or desirable to have any large quantities of materials stored in the laboratory. Their proper place is in the storeroom where they can be supervised. Laboratory reagent bottles can be limited to not more than a liter.

The handling of samples is apt to be a problem, particularly in industrial control laboratories, and provision should be made in the advanced planning for the filing and storage of large numbers of samples in uniform containers either in cabinets or in racks.

FURNITURE, FLOORS AND FUME HOODS

The working arrangements in the laboratory proper will have much to do with the safety as well as the convenience of the work carried on. The height of the working surfaces should be carefully considered with respect to the size and nature of the operations to be carried on. It must be decided beforehand whether it is more desirable to work at any particular type of job at floor level, as is best with most large physical apparatus and most large-scale chemical reactions, or whether it is better to sit at a low bench or stand at a high bench. For most student laboratories versatility is more desirable than efficiency and tables or benches of a standard height will be used. For more specialized work in commercial or industrial laboratories or research laboratories the working height should be tailored to the particular job in hand. The arrangement should be such that instrument readings can be taken at or near eye level without standing or climbing on temporary or improvised supports. Arrangements should also permit the control of apparatus and the handling of materials at a convenient height, preferably between waist level and shoulder level. Provision should also be made for having the apparatus and equipment firmly supported and fastened down either by plates permanently mounted in the walls and floor or by racks permanently mounted on the benches or tables.

Services such as electrical outlets, gas lines, water lines, air and vacuum connections should be grouped so that they can be easily reached in case of an emergency. If they are grouped at the back of the apparatus or on the back of the laboratory bench as is common in many laboratory set-ups there should be unit controls at the end of each laboratory bench or near the exit from each laboratory unit which will close down the whole unit in case of necessity.

The materials for construction of benches and equipment should be flame resistant insofar as possible. Wooden benches should have flame resistant tops at least. Bench tops may be flame resistant and insulating, as stone tops or metal tops separated from the wood by a layer of insulating materials. The materials chosen should also be as impervious and non-corrosive as possible.

In laboratories where mercury is to be used in considerable quantities the bench tops should be impervious and free from seams or cracks, or with the seams and cracks cemented. They should also slope to a sump at the rear from which spilled mercury can be recovered. The floors in such laboratories should be impervious and without seams or with carefully cemented seams. Flooring materials should be continuous in a round cove up the wall and up the side of permanent furniture and equipment for a distance of 4 to 6 inches. This will make it easy to pick up spilled mercury and will prevent the accumulation of large quantities of mercury in the structure. It has been shown that an area of mercury of approximately four square inches exposed to the air in a small laboratory can produce a concentration of mercury vapor in the air of 2 milligrams ten cubic meters.* So it is evident that this is a necessary precaution. A porous floor exposed to spillage of mercury will retain a large quantity and eventually will have to be replaced or covered over for the safety of people working in the laboratory.

In constructing impervious floors for laboratories a good material is heavy linoleum with the joints well cemented. Glazed brick, tile, terrazzo or rubber or plastic tile with the joints well cemented are all useful materials for the purpose. The tiles which come in relatively small squares are convenient because of the ease of making repairs in case of damage but it is somewhat troublesome to keep the joints cemented. Whatever floor surface is used its slipperiness, particularly under the wet conditions which are likely to prevail in laboratories should be considered and care should be taken to provide a surface which is not dangerous to walk upon. Any of these materials can be provided with finishes which are not dangerously slippery under dry conditions, and most of them also can be provided with surfaces which are not slippery under wet conditions. Even ceramic tiles can be produced which are both impervious to the penetration of liquids and are not dangerously slippery under wet conditions.

Resilient flooring materials, such as linoleum or asphalt, rubber or plastic tile, generally have to have some maintenance material applied to protect the surface. These maintenance materials also can be obtained in varieties which are not unduly slippery. The Underwriters' Laboratories have been rating and listing floor maintenance materials according to their slipperiness for a number of years.

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* Mercury, Industrial Data Sheet D-Chem. 17, National Safety Council, Chicago, Ill.

In laboratories where the operations are inherently noisy, such as engine test laboratories or in locations where there is inherently noisy machinery such as crushing and grinding equipment or burners with forced draft, preference should be given to the softer floor and ceiling surfaces. These help reduce the propagation of noise. For the same reason such locations as these should be sub-divided into relatively small units and operators' locations surrounded by sound deadening materials should be provided. Long continued exposure to any sound level over 100 decibels and to high pitched sound levels somewhat lower is said to produce an occupational type of deafness. The plan should be set up to reduce the worst noise levels at operating positions to below 100 decibels.

For laboratories where toxic or irritating gases or vapors are going to be produced, local exhaust fume hoods should be provided in sufficient numbers to take care of all of the equipment which will be producing such effluents. For chemical laboratories, glazed brick, tile or soapstone are the materials recommended for the lower part of the hood while a shatter-proof glass or wired glass is recommended for the doors. The upper part of the enclosure may be of asbestos cement or metal to reduce construction cost. In areas where the reactions to be carried on may be explosive or where equipment is to be used under vacuum or pressure, doors should be of shatter-proof glass. Such doors also should slide horizontally so that they can serve as a shield between the operator and the reaction. If materials are to be used in the exhaust hood which may ignite or explode deposits in the hood or the ventilating ductwork, the system should be provided with means for flushing out the duct work and the ventilating recesses in the hood with water. Well known examples are perchloric acid and paranitraniline either of which may produce an explosive mixture with oxidizable matter in the duct work. Perchloric acid has caused a number of explosions which have resulted in both property damage and injuries, while paranitraniline has caused fires in duct work.

The ventilating equipment for exhaust hoods, particularly perchloric acid hoods, should not be provided with any dampers or other means of regulating or cutting off the flow of air. The system should be designed for the maximum hazard to be expected and should be operated at design capacity at all times. If the duct work is designed for proper air velocity it will be essentially self-cleaning. If the flow of air is cut down the velocity in the duct will necessarily be reduced and the probability of building up dangerous deposits in the duct work will be correspondingly increased. For most chemical operations where the gases or vapors are released into the air without any noticeable velocity the hood should be designed for a face velocity of 50 to 70 feet per minute of air with all doors open.

The utility services to exhaust hoods in chemical laboratories should invariably be controlled by switches and valves outside of the hoods.

HIGH PRESSURE LABORATORIES

With the modern tendency toward high pressure operations, consideration should be given to the provision of safe quarters for bombs, autoclaves, and other vessels under extremely high pressures. For very high pressure work a separate building should be provided, preferably of single story construction with an outside exit from each work area and with each major piece of pressure equipment in a separate cubicle. The cubicle should preferably be of reinforced concrete with a light roof to vent an explosion upward or with one light, non-bearing wall, such as glass in explosion venting sash, to vent an explosion in controlled direction.

Medium pressure equipment, such as ordinary autoclaves or vulcanizers, can be safely operated in the general laboratory but should be in a separate room to localize the damage in case of accident.

X-RAY LABORATORIES

Much x-ray equipment is now being used in laboratories both for crystalographic and other x-ray defraction purposes and for direct radiographic inspections. Both the radiation and the electrical hazards of such equipment should be provided for in the original design of the building so that the structure will be made completely protective against the radiation hazard by means of concrete barriers, lead barriers or both. The electrical equipment should be protected by complete enclosure interlocked to prevent its operation when anyone is within the enclosure. The detailed instructions for the planning and testing of such installations are given in the Safety Code for the Industrial Use of X-rays.* Even with the best planning it is necessary for complete protection of personnel not only to test such installations after completion but to monitor them continuously or at frequent intervals. The science of protection against x-rays is not sufficiently well developed to make it possible to predict with certainty all the effects of the radiation when the installation is planned. This is particularly true in the laboratory where use is likely to be extremely variable. Even a careful inspection after installation will not necessarily reveal the hazards which may occur during the regular use of the equipment.

MECHANICAL GUARDING

Many types of testing laboratories require the installation of much mechanical equipment. The installation of such equipment should be planned so as to give adequate room around it for operation and for safe passage of individuals moving about the laboratory. Excessive crowding of equipment is a prolific producer of mechanical accidents. It is all too common to see equipment installed in laboratories in such a manner that in operation moving parts extend out into aisles which may be adequate when the machine is not operating. In some cases moving parts are exposed to contact by people working on the machine or to those passing by it. Moving parts of all mechanical equipment should be fenced off from contact by means of standard hand rails with toeboards or should be enclosed in stationary guards. Safe Practices Pamphlet No. 110* gives suggestions for practical methods of accomplishing the guarding of the power transmission equipment as well as for guarding points of operation against contact.

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* American War Standard 254-1—1945, American Standards Association, 70 East 45th Street, New York 17, N. Y.

SAFETY PRECAUTIONS

Wherever there is a possibility of clothing fires or of splashing corrosive chemicals, emergency showers should be provided for the laboratory personnel. These should be located, preferably, in the hallways close to the doors of the individual laboratories or in the centers of large laboratories. They should be of the deluge type with large openings to give coarse streams and should be supplied by at least a one-inch supply pipe. The valves should be of the quick acting type that are controlled either by stepping on the platform under the shower or by a pull chain suspended beside the shower. If a pull chain is used it should terminate in a loop fastened to the wall or ceiling. In this way, a man may operate it by hooking his arm or any part of his body through the loop and throwing his weight on it instead of having to look for a chain end.

For extinguishing clothing fires from volatile flammable liquids woolen blankets may be provided. Such blankets should be of the type which are stored in a vertical container on the wall with a handle extended so that it is necessary only for a man to seize the handle and turn himself about to be completely wrapped up in the blanket.

It is desirable that the laboratory be provided with a complete sprinkler system for fire protection. In some places it is undesirable to have a deluge of water but even these areas can be provided with sprinklers to keep a fire from spreading and the vital points can be protected by shields to keep water off. The minimum protection is an adequate number of chemical fire extinguishers. These should, preferably, be placed near the doors of the individual laboratories, or, at any rate, at a reasonable distance from the principal fire hazard so that they will be actually available in time of need. For electrical fires, carbon dioxide, dry powder or vaporizing liquid extinguishers should be provided. The latter types or foam extinguishers are useful for chemical fires in materials insoluble in water. The water types of extinguishers are useful for fires in ordinary materials. Ordinary foam extinguishers should not be used where water soluble flammable liquids are the hazard because these liquids generally destroy the foam.

LIGHTING

For ordinary laboratory purposes the lighting should be planned to give general illumination of 30 to 50 foot candles with local illumination for areas requiring higher levels. Ordinary electrical installations are sufficient except in areas of very high fire hazard where the installation should be in accordance with Article 500 of the National Electrical Code.

The best source of general safety information is The Accident Prevention Manual for Industrial Operations published by the National Safety Council. Another excellent source, including fire protection, may be found in Section 30 of "Chemical Engineers' Handbook", edited by John H. Perry, 3d ed., McGraw-Hill Book Company, Inc., 1950. The section also contains a comprehensive bibliography. An informative discussion of the subject is the paper on "Laboratory Safety" by H. H. Fawcett which was presented at the American Chemical Society Meeting in Detroit in 1950.

For information on toxicity of materials commonly used in the laboratory the American Chemical Society Monograph "Noxious Gases and the Principles of Respiration Influencing Their Action" by Henderson and Haggard, published by the Reinhold Publishing Corporation, is very good, as is Sollmann's "Manual of Pharmacology", published by W. B. Saunders Co., Philadelphia.

*** Mechanical Power Transmission Apparatus, Safe Practices Pamphlet No. 110, National Safety Council, Chicago.**

Part II

TEACHING LABORATORIES

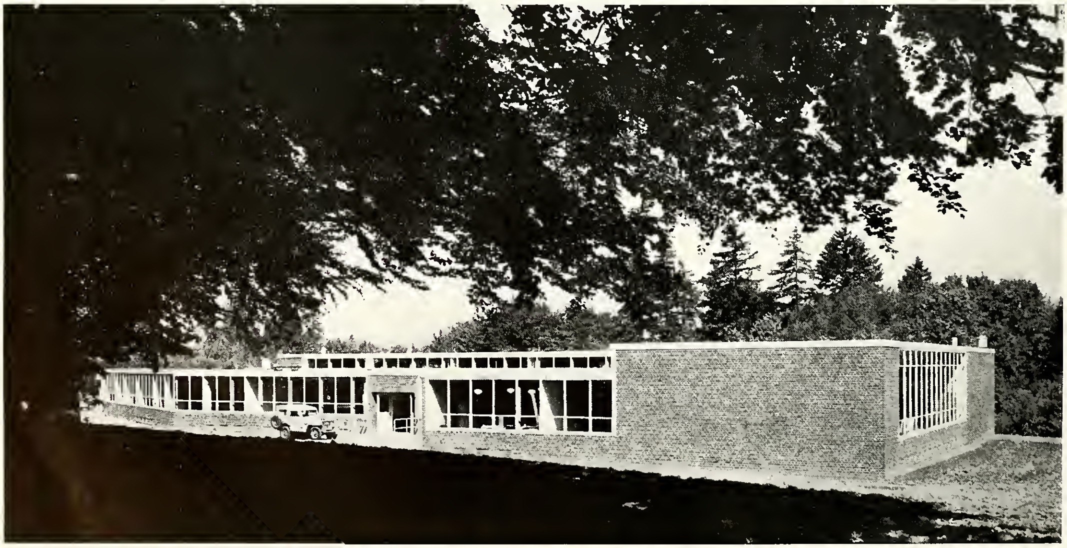

Figure II.1 New Chemistry Building of Reed College.

1

SITE SELECTION, DESIGN AND CONSTRUCTION

Harry F. Lewis The Institute of Paper Chemistry, Appleton, Wisconsin

The 1930 edition of the report of the National Research Council on "Construction and Equipment of Chemical Laboratories" was directed toward a description of teaching laboratories, since the years immediately preceding 1930 saw the building of a large number of university and college laboratories. This period was also marked by the beginnings of many industrial research departments, housed at first in facilities already available; these had established themselves by the next decade to the point where new quarters had to be provided. The last 25 years have been marked by a great increase in the number of industrial laboratories built, as well as laboratories for research institutes, government departments, and academic purposes.

The experiences developed from building and using these laboratories will be of great help in the planning of future construction. Most chemical laboratories are built to serve a particular situation. This is as true for teaching laboratories as it is for industrial laboratories. Buildings have to fit the limitations imposed by the site, the amount of money available, the prevailing architectural style, the particular group being serviced, the size of the staff and the number of students registered in the department, and the research interests of the staff to be housed. Because of these and other limitations, it is not possible for a volume of this kind to provide any easy answer and complete plan for each specific situation; rather, it serves to point out the types of problems to be considered, to provide the basic information which the reader can apply to his own project, and to describe in some detail what others have done to service their own needs. As a first step in this direction, the Division of Chemical Education of the American Chemical Society put on a symposium on the "Design and Construction of College and University Chemical Laboratories" at the Atlantic City meeting of the Society in 1947.* At least a part of the material in this section has been adopted from the papers presented at that symposium.

It is the plan of this volume to review first the general considerations which obtain in the starting of the building project; this will be followed by detailed discussions of laboratories of general and specific types.

The steps followed in building a college or university chemical laboratory are somewhat the same in kind regardless of the type of school. In the early stages several groups of people may be concerned. One group may select the site, basing the decision on available land, location of other departments being serviced by chemistry, or servicing chemistry (agriculture, medicine, physics, and the like), esthetic reasons, or no reasons whatever. Members of the department in question may or may not be given the opportunity to express a preference or for appraising the decision. A second group may have the responsibility for selecting the architect (in many cases today, particularly in the larger universities, the school will have its own architect and he and his staff may do the planning for the specific building or he may serve as a consultant to represent the school in selecting and dealing with an outside architect). The first and second groups may be the same, having the responsibilities of an over-all campus-planning committee and the functions of the building committee of the Board of Trustees of the school. Finally, in most cases a building-planning committee is set up, composed in part of men from the department concerned, whose function varies with the school. Usually this committee develops information in advance of a meeting with the architect relative to such subjects as the courses to be taught, the number of students to be accommodated in each course, the number of laboratories required for each course and the minimum sizes in square feet, the number and capacity of classrooms, the number and capacity of lecture rooms, the number of staff offices, department head offices and administrative space, space for the library, and for miscellaneous rooms.

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* J. Chem. Education, 24:320-53 (July, 1947).

Although the site for the building may already have been selected by the first group mentioned above, the building-planning committee should have the privilege of checking certain features. The nature of the terrain should be reviewed with particular reference to accessibility to trucking roads, transportation facilities, parking space, main lines of service for gas, water, and sewage, freedom from vibration, external fumes, smoke, fly ash and dirt, and noise. The location of the building to the windward side of the boiler house is bound to put a heavy demand on the scrubber equipment in the ventilating system (and may lead to the contamination of student experiments in spring and summer via the open window). The ideal site is rarely achieved but, if a compromise is necessary, the building committee should be in on the decision.

A further factor in connection with the site deals with the directional position selected for the new building. In most parts of the United States and with most buildings, there is much to be said in having the long axis of the building run east and west. This gives the desirable steady north light for certain types of work and the more intense southern exposure for the large laboratories. For one-floor buildings in small colleges it is possible to orient the building so as to utilize the morning sun for lighting lecture rooms and offices and the afternoon sun for the laboratories which are used principally in the afternoon but, even here, the east-west axis is generally satisfactory.

Assuming that the site of the building has been selected and figures as to the use and capacity of the building have been established, consideration should next be given to the plan of the building. Whether it is to be a one-floor structure, one of several floors, or a skyscraper will depend on such factors as available space, type of school, number of students to be accommodated and funds available. The small school, where the instructors must double up on subjects for which they are responsible, can best profit by the one-floor building. Such a building would seem to be ideal for a department of 200 students or less and a staff of two or three men. The features of this type of building have been described in the literature and need not be covered in this volume. Briefly, the plan is based upon the concentration of lecture room, recitation room, library, and staff offices and laboratories in the front of the building and the student laboratories in the rear, built in close contact with the central service area of stock room and rest rooms. This permits increased efficiency in handling supplies and in supervising laboratory sections. This type of building is particularly adapted to the use of functional design and modern construction. Partitions between laboratories may be of the movable type, using either steel panels set between metal posts or asbestos cement sheets hung on light weight metal studs held in place by metal channels in the ceiling and floor. By substituting glass for steel or asbestos between the 3-foot and 8-foot levels, it becomes possible for the stock room man or any instructor to check conditions in the laboratories at any time. It should be pointed out that, in a plan of this type, the sawtooth roof construction of the industrial laboratory is not needed; large window spaces provide the necessary lighting, and ventilation can be provided in large part through the use of unit ventilators. The cheapest kind of wall construction for the region may be adapted. The most recent illustration of the adaptation of the one-floor building to the needs of the small college is the new chemistry building shortly to be put in use at Reed College, Portland, Oregon (see figure II.1).

For the larger colleges and universities, a single-floor building will not be either the most effective or the most economical. The more nearly cubical building usually is the cheapest to build; a compromise between cost and arrangement is generally necessary. The advantages described for the functional one-floor building may be utilized in a building of several floors. The new chemical laboratory of the Illinois Institute of Technology has been built at a surprisingly low cost in these times of high prices. Figure IV.2 gives an idea of the appearance of the building. A fuller description will be found on pages 238-243.

The time required for planning in order to reduce to a minimum unnecessary running around by either staff or students is time well spent. The average instructor has only so much time to divide between teaching, study, and research, and those who plan buildings should see to it that the time in each category is effectively spent. The individual idiosyncracies of the instructors currently teaching should not be allowed to set the behavior pattern of instructors to follow them in the use of the space and facilities.

The next step after agreement on the type and size of building is the establishment of the general exterior design. This is largely the business of the architect but the building committee must of necessity be concerned for very frequently the exterior design sets the interior pattern in an inflexible mold. Irregular arrangements of windows in the interest of some architectural function or small windows with deep recesses may make for an unusual and interesting appearance, but they may work havoc in the effective arrangement of laboratories. This has actually happened in a number of cases. The exterior should be in accord with the interior, and this is fixed by the laboratory unit size where even distribution of light is desired and achieved. The unit consists of an aisle between two chemical benches, together with the benches servicing the aisle. The new General Electric Company Research Laboratory at Schenectady may be cited as an illustration; here the unit size of 12 feet was adapted as standard with windows 5½ feet wide and pilasters of 6½ feet. Since the average laboratory table is 24 inches from edge to center services, this provides 2 feet of laboratory bench space with an 8-foot aisle. This is somewhat wider than that used in the average teaching laboratory where aisles of 5 or 6 feet are considered sufficient, making the unit either 9 or 10 feet from window center to window center. Later chapters cover this subject in detail; it is mentioned here to indicate why the building-planning committee should have an active interest in the design of the exterior.

In connection with the over-all planning of the building, the committee should give careful thought to the problem of getting the maximum working space, the minimum waste space, and the best facilities to meet the needs from the money at hand. It is realized that it may not be within the province of either the architect or the committee to satisfy completely this aim, since the donor of the building or the trustee committee (or in some cases the president of the school) may insist on a building in exact conformity with the other buildings on the campus in spite of the fact that this may mean the spending of money for nonproductive space. When it is possible to do so, the committee should consider contemporary design. During the past few years this type of design has been applied to the building of industrial plants and laboratories with considerable success from the standpoint of architectural interest. Functional buildings may be modified to harmonize by using the same materials of construction as are used on the exterior of existing buildings where some definite campus pattern obtains. As was pointed out in one of the papers on the Atlantic City symposium,* "We Americans are an inconsistent race. We require the architect to design 'period exteriors' and in almost the same breath demand modern interiors." It would seem possible to surround these modern interiors with satisfying exteriors. High ceilings and large halls, small windows and dark laboratories, fumed oak woodwork and gaudy exteriors should have no place in current campus planning.

As another step in the operations of the building-planning committee some consideration must be given to materials of construction for hall and interior partitions, ceilings and floors. The location of main service lines so that they will be easily accessible, the need for elevator service and stairs, whether air conditioning should be included, and the most effective location of various types of rooms such as service rooms, stock rooms, and rest rooms are other matters of importance to the committee. In considering the plan, it is important that the faculty building committee advise the architect as to the probability of the need for expansion in future years and the direction of such expansion. Only in this way can additional space be provided without the disruption of important services. Here it is necessary to consider the expected increase in student enrollment, in staff, and in research operations. As these expand, storage and service facilities must expand likewise.

Another important aspect of the plan is the location of the lecture rooms and recitation rooms with respect to distracting outside noises, such as coal chutes, unloading facilities for express and freight, and probable student gathering places on warm springs days. Likewise in placing research laboratories, libraries, and other rooms, thought should be given to preventing as much distracting inside noise as possible. Balance rooms and laboratories concerned with the use of delicate instruments should be protected from fumes and vibration. All of these points will be discussed in greater detail under the appropriate sections to follow.

One important point commonly neglected in the planning of a laboratory building has to do with the size of the library and its projected expansion. It should be possible for the building committee to advise the architect with a reasonable degree of certainty both as to the current shelf space requirement for unbound and bound periodicals and reference books and also for the probable expansion in feet per year for new periodicals and new books. If the building is projected for 30-year use, library expansion should be set up on that basis. There are many supplemental services associated with the library which seem to come to mind after the plans are drawn and the building is built; these include such things as film reader service, photostat service, and carrells for advanced students and faculty. One real annoyance in departmental libraries is the library attendant who has to do her typing in the reading room. In the planning it should be possible to make provision for work of this type by building either an acoustically insulated alcove or arranging the room in such a way that the librarian's assistant is behind a plate glass window with vision of the room. Routines of the departmental library operation are generally established for the chemistry department by the library staff, and they should be called into consultation in the planning of the chemistry department library.

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* **H. R. Dowswell, J. Chem. Education, July, 1947, p. 352.**

Real attention should be paid by the building committee to the services and to staff and student comfort and convenience in the lecture and recitation rooms. Here of all places, it is important to provide comfortable seats, adequate lighting, good acoustics, and proper ventilation. There is no reason today for any chemistry lecture or recitation room to be lacking in any of these features; yet, as one visits the various chemistry departments, there seems to be less thought paid to the design of the lecture room than to many of the other features in the building. Equipment for demonstration should be visible from all parts of the room. Fume ventilation should be provided in the demonstration area. Slide and film projection housing should be handled in the original planning and not as an after thought. Outside speakers appreciate the convenience of automatic projection equipment operated from the lecture table by the mere pushing of a button. Careful consideration should be given to the method of darkening the lecture room for opaque and slide projection, although at the same time there should be sufficient light for students to take notes. Air conditioning is highly desirable but the system selected must be quiet. Acoustical treatment should be provided in the ducts on the ceiling and, if necessary, on the walls. Sleeping students do not always mean a dull lecturer.

Much more attention has often been paid to the design of laboratory equipment than may seem necessary; it sometimes appears as though every college professor feels he is especially called upon to design laboratory furniture. There was a time when every installation was different from every other installation; no two rooms within one installation were the same. The actual differences in design are often small and unimportant to all save the planner. This makes interchange of equipment between divisions of a department difficult and may greatly increase the cost. The situation is changing, however, partly because of the pressure of the times and partly because of the trends toward providing laboratory space for common use by two or more different courses. In the section of this report devoted to laboratory furniture, considerable attention is being paid to the matter of furniture design and emphasis is placed upon the desirability of ordering units described in the catalogue of the furniture companies. The manufacturers of laboratory furniture have spent a vast amount of time studying the needs of chemical laboratories and have been hard at work improving their products. Although they are not yet all that may be desired, careful construction and attention paid to the specifications should lead to the installation of a very satisfactory product. The various manufacturers of laboratory furniture will be glad to furnish detailed information with regard to their specifications and tests of their finishes and various products.

The building committee will probably have to decide on: materials to be used in the desks in the laboratories—whether they should be wood or steel, materials for tabletops, the fume ventilation—whether individual hoods or large hoods to handle groups of students should be used—how the service piping from feeder lines should be brought in, the unusual services that might be required by the laboratory courses given in the room, the kind of floor covering to be used, and the kind of lighting that should be installed in the laboratories, lecture rooms, and halls.

In addition to the usual laboratory services, there are special services for which provision must be made in planning a building. One such is glass blowing. Many universities have a glass blower with a room provided for special work; student glass blowing is generally done in the open laboratory. One of the most distracting noises in the laboratory is a blast lamp. Why should not the glass blowing bench either be provided with good sound insulation, or one of the quiet glass lamps be made available for student use? Most research laboratories today seem to need constant temperature and constant humidity facilities. The up-to-date laboratory provides special rooms for micro- or semimicro-analysis. Dark rooms are required for photomicroscopy and photochemistry, as well as for electron microscopy, spectroscopy, and spectrophotometry. Detailed consideration will be paid to these facilities in a later section. In any chemistry building there are the service rooms to consider. Adequate rest rooms should be provided for men and women, with separate rooms for students and staff. Industry is ahead of educational institutions in recognizing the need for providing attractive and adequate facilities. Adequate and convenient storage space is needed by the maintenance staff for supplies, hazardous chemicals, and heavy equipment. This space should not be made a last minute item in the planning. A study should be made of the most effective type of dispensing service for chemicals and glassware. Generally just enough space is set aside in these categories to meet the immediate needs at the time of the opening of the building, and no thought is given to the fact that the space needed for the storage of supplies will increase at a greater rate than might be expected. For one thing, there is a constant purchase of special equipment for staff research projects. Such equipment seems never to be dismantled but is always kept in storage for the time when it might again be required. Dead storage space should not be expensive space; in fact, there is no real reason why dead storage should be provided within the confines of the laboratory building. If a dishwashing service is to be installed to service the research laboratories, provision should be made at the time the building is planned.

Adequate provision should be made for departmental and staff offices. It is common practice to install a laboratory bench in an instructor's office under the assumption that the faculty man will wish to do his research in his office. Industry has found this to be a mistake in most cases when the man involved has administrative functions. It probably is a mistake for educational institutions, too—particularly the larger ones. What happens is that the faculty man thinks he will do his own work, gradually gets away from the laboratory table, either brings in a graduate student to do the work (and then the room is no longer available for private faculty student conferences), or else piles the table high with issues of *Chemical Abstracts,* catalogues of laboratory supply houses, student reports, and bound copies of Master's and Doctor's dissertations. The result is distraction. It is much better to provide offices adjacent to the research laboratory, such as has been done to good advantage in many industrial and government laboratories, and equip them attractively with book cases and file cabinets in addition to desk and chairs. Consideration should be given in the planning of a chemical laboratory for small rooms for interviews. Although the tendency is to have interviews handled through some central personnel office in the university, there will always be a demand for interview rooms within the chemistry building itself. It is better to have a room for the purpose (and one which may serve other purposes as well) than to use the stairway or a stool in a large laboratory or a corner of a classroom as the place where the prospective employer first meets his prospective employee.

Many industrial laboratories have a fire-protected vault for research notes and valuable records. Educational laboratories might profit from such an installation for academic and research records and other valuable papers. Consideration should be given to adequate fire protection for students and staff and for the building. Sprinkler heads have many advantages; safety showers, fire blankets, and fire extinguishers should be easily available. Asbestos suits should be stored in prominent positions where they can be reached easily in case of an emergency. Plans should be made for the adequate housing of material of this type in advance of the construction of the building. Every building, whether large or small, should have some kind of first-aid facilities, preferably a room equipped and used for that purpose alone.

There are many other problems which have not even been approached in this introduction to the subject of the planning of the teaching laboratory, but primary consideration should be given to the objective of an attractive, well ventilated and lighted, acoustically satisfactory building. Halls do not need to echo to the march of tramping feet, offices and classrooms do not need to reek with the memory of by-gone experiments, laboratories need not be reminiscent of antique shops; resistant laboratory finishes, both light and attractive, are available. Lecture room chairs do not have to speak and groan in vocal protest to the unhappy squirming of the uncomfortable occupant. An ounce of prevention is worth many pounds of cure. It is up to the building committee and the architect to plan a building which will serve its purpose just as well after thirty years of occupancy as when it was constructed and which may be maintained easily and at not too great a cost. This can be done, for it has been done; a good illustration is the Charles James Hall of Chemistry of the University of New Hampshire which was opened for use in 1929 and today (20 years later) it gives the visitor the impression of a new and extremely satisfactory building—a tribute also to its architect, E. T. Huddleston, Professor of Architecture at the University of New Hampshire.

2

INTERIOR ARRANGEMENTS

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Each school has its own particular problem to solve in planning a laboratory building. The ideas, purposes and teaching objectives of such different schools as teacher's colleges, co-educational schools, women's colleges, technical schools, universities, agricultural schools and other schools, plus the questions of location of the building, topography, availability and valuation of the land, financial condition and size of the school, will naturally result in special planning considerations. Also, the character of the internal arrangement of rooms, furnishings and services selected by the planning committee tend to be a heterogeneous composite of the individual preferences of the particular staff who happen to occupy the building at the time the laboratory is planned. The result is that no two laboratory buildings will be alike.

There are advantages and disadvantages in this situation. It permits the various ideas of planning committees in different schools to be tried out in practice, even though this procedure often results in expensive experimentation. The disadvantage is that it often prevents standardization in construction and creates many unnecessary problems for the laboratory furniture companies who would like to manufacture their product on a production basis.

Because of the many variables involved in planning the interior of a laboratory, only those basic planning principles which appear to be common to most laboratories will be considered here.

It is the job of the planning committee to collect the functional information leading to the rough floor plans of the laboratory building, the many details of the laboratory, library and office furniture, the plumbing and electrical services, and the fume hoods and exhaust systems.

In general, planning committees have certain limitations. Usually they are not specially trained for the job. It is probably the first time they have ever planned a laboratory building. Sometimes they are highly conditioned and influenced by the old facilities and equipment with which they have worked, and the resulting plans are usually a composite reflecting the teaching attitudes and idiosyncrasies of the individual members of the committee. Even so, some remarkably well planned laboratories have resulted from their deliberations.

FLOOR PLANS

Modern laboratory buildings are planned from the inside out. To do this job objectively the committee must first assemble certain information leading to the rough floor plans of the building. The following suggestions and considerations in obtaining and applying this information are submitted.

1. The committee must obtain from the college or university administration any formulated or anticipated long-range plans with respect to growth or changes in enrollment, involving both the undergraduate and graduate schools. They must find out whether increased or decreased emphasis in the sciences is to be expected, whether provision should be made for private research

laboratories, etc. By plotting out the class and laboratory populations in the several courses over a period of several years some projected idea of the size of laboratories and lecture rooms can be obtained.

2. The committee should know whether funds for the laboratory building are assured, and, if assured, whether they are limited or some latitude is permissible. If not assured, a well worked out plan for a laboratory building is the best way to sell the idea to prospective donors or to the trustees of tax-supported schools.

3. The committee should visit a number of the more modern teaching and industrial laboratories in the region. At the present writing approximately 200 colleges and universities in the United States have either built new laboratories, or they are now under construction or plans for them have been formulated. Such trips help not only to educate the committee on how others have handled similar problems but the information gained helps to facilitate subsequent deliberations of the committee and enable it to reach reasonable compromises.

If an architect has been appointed it is well that he accompany the committee on these trips. In many cases it is the architect's first experience in planning a general science or chemistry laboratory. Modern science laboratories are unusual buildings requiring specialized knowledge of plumbing and electrical services, ventilation, fume-hood systems, etc. Also, few plumbing and electrical contractors have had previous experience with such specialized buildings.

4. There is a group of manufacturers who do specialize in equipping science laboratories, namely, the laboratory furniture companies. Unfortunately they are usually called in after the overall plans of the buildings have been completed. It is strongly urged that the planning committee consult with a specialist from one or more of these companies during the preliminary planning period. This is particularly important because one of the first decisions the committee must make is the dimensions of the functional module which in turn is most often based on the dimensions of the laboratory table unit as later described.

5. As a prelude to floor planning the committee should review the available literature on laboratory construction. They should consult other chapters of this volume. The contributions to two symposia* on this subject should also be consulted.

6. Before working out the details of the floor plans the committee must agree upon the type of laboratory building. Some of the factors involved in this decision are location of the building, topography, the prevailing architecture of the campus, whether a one-story or multi-story laboratory is indicated, whether a flat or pitched roof is desired, and whether air conditioning, involving laboratories with or without windows, is contemplated. Some of these factors will be considered further.

One-Story or Multi-Story Laboratory: If there is plenty of space and the land is not too valuable, the one-story laboratory with saw-tooth roof seems to have some advantages over the multi-story type. Among these advantages are light weight, and resultant economy of construction, elimination of elements of vertical circulation which, in comparison with those of horizontal circulation, are always complicated and costly, and the inherent advantages of a low building, namely, orientation and avoidance of large areas of shadow.

Also, in permitting all working laboratories to be at or near the ground level, the one-story building allows greater stability for chemical balances, galvanometers, and other instruments affected by vibrations. It permits quick evacuation in the case of fire and saves the energy of both faculty and students in going up and down stairs. Panel or radiant heating is peculiarly suited to one-story laboratories, consequently radiators, which often utilize valuable space and clutter up rooms (unless recessed), can be eliminated.

The one-story laboratory also results in an enclosure with two opposite and important sides—a top and a bottom—which, because they would never be common to other enclosures of the kind, would allow considerably more freedom to the architect when the disposition and arrangement of service elements were considered. Through a carefully planned system of floor trenches with removable covers, all plumbing, drainage, and electrical services can be made accessible. Such a system contributes to the important requirement of flexibility. The exhaustion of hoods through comparatively short fume ducts to the roof is also facilitated.

Inherent disadvantages of the one-story laboratory are loss of compactness, increased amount of land necessary, increased amount of footings, increased roof area, and increased dependence upon mechanical means for distributing air, water, chemical drainage, and sewage, since there is less opportunity for gravity flow. Also the one-story laboratory does not permit the architect much latitude in his architectural treatment.

In general the one-story laboratory appears to be well-suited for the undergraduate problem in large universities. There is less student congestion as compared to that of tall buildings. In some instances large universities have found that a number of smaller one-story laboratories meet their general chemistry problem best. It permits sectionizing in smaller laboratories and helps to remedy the feeling of mass education on the part of the student. However the separation and isolation of general chemistry laboratories from other undergraduate and graduate laboratories does not achieve that integration which many schools consider important.

Laboratories With or Without Windows: Windowless buildings are strongly indicated in cases where the rigid control of working conditions, such as temperature, humidity, lighting, etc. is desired. Such buildings lend themselves to panel heating and have more wall space for hoods, blackboards, reagent shelves and storage cabinets, and other laboratory services. Also, wall space permits a greater opportunity for visual education.

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* "Symposium on the Construction and Design of Research Laboratories." Industrial and Engineering Chemistry, 39, pp. 440-461 (1947) and "Symposium on the Design and Construction of College and University Laboratories." Journal of Chemical Education, 24, pp. 320-353 (1947).

Windowless buildings are easy to insulate and air condition; thus they permit uniform control of temperature and humidity throughout the year. This is important for the control of constant temperature baths, calibration of volumetric flasks and burettes, and many other precise physical and chemical measurements. Most new laboratories are air conditioned.

On the other hand it can be argued that a building without windows is not so dependable as one with windows. Such buildings depend on mechanical supplies of light and air and if for any reason the machinery ceases to function the building cannot be used, whereas a building with windows can always be inhabited somehow. Besides serving their ordinary function windows provide an emergency exit in the case of fire and give way in the case of a serious explosion thus saving the walls.

It can also be argued that landscape views from windows offer the student relief from concentration, but teachers find it difficult to tolerate distraction. If windowless laboratories are desired, the selection of the proper color scheme and interior decorations will largely offset a need for relief from a feeling of confinement. Psychologists may help us with this problem.

The new Firestone research laboratory in Akron has been so planned that the perimeter of the building containing windows is reserved for offices, library, stairs, etc., whereas the laboratories in the interior of the building are windowless. The result is a daylighted office building which serves as the enclosure for a windowless air-conditioned laboratory building. The idea might be well-suited to the problem of the university laboratory with its graduate and undergraduate requirements.

The Flat or Pitched Roof: It is difficult to make out a case for either pitched or flat roofs on laboratory buildings. The prevailing architecture of the campus may be the deciding factor.

The pitched roof provides a natural insulation over the rooms below and serves as space for certain service elements such as ventilation ducts and hood vents. However, it is difficult to avoid waste cubage in pitched roofs and this costs money. Two separate surfaces have to be supported independently—the floor or ceiling over the rooms below, and the surface of the roof itself. If the plans call for the distilled water to be prepared from cistern water (collected from the roof of the building), then a slate roof gives a better quality of cistern water than that obtained from tarred flat roofs.

On flat roofs an entire unfinished service floor can be built to the required height of the service elements and thus the cubage enclosed can be better utilized.

Influence of the Campus Architecture: College and university laboratories in the past were frequently planned by the school administration and the school architect, who were much more interested in building a monument to the donor and preserving the prevailing architectural type on the campus than in considering the function of the building. As an afterthought, it seemed, the chemical laboratories were somehow tucked in.

The modern science laboratory should be designed to fulfill the functional purpose of the building and the architect should permit this purpose to be expressed in the exterior treatments. The form should develop from its function and the exterior treatment evolve logically from this plan. If the exterior treatment so evolved lends itself to adaptation to the architectural tradition of the campus, well and good. In modern science laboratories, art and aesthetics should be considered functions of utility.

Unfortunately in many laboratories being built even today planning committees have failed to convince the board of governors of the wisdom of this advice, and Gothic or Georgian exteriors have greatly restricted and cramped the functional operations of the building.

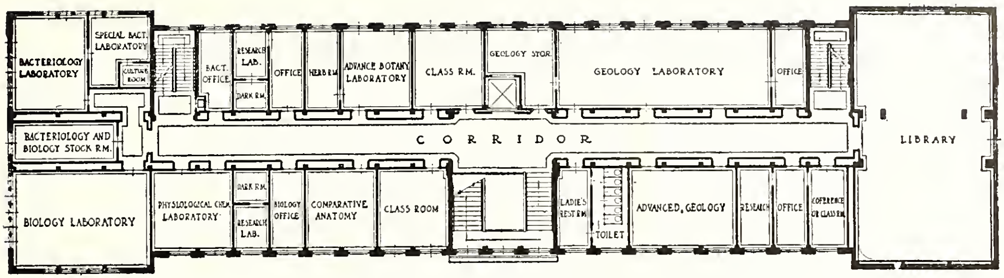
Certain basic planning principles should be observed in planning modern science laboratories.

Selection of the Module or Laboratory Unit: The committee must agree upon the size of the building module or laboratory unit. In large universities or technical schools where the graduate laboratories are separated from the undergraduate laboratories, it may be desirable and architecturally permissible to employ different modules for each of these laboratories. The module will determine the distance between bays or columns, the size of offices, in multiples the size of laboratories, collectively the building perimeter, and finally the architectural possibilities of the buildings. The free use of the module in the floor plans will reduce waste cubage, permit standardization of laboratory furniture and services, contribute to flexibility and reduce costs.

A considerable difference of opinion is found among teachers as to the size of the module; it varies from about 9'0" by 21'0" to 15'0" by 25'0". In general, the size of the module may vary depending upon the principle function of the laboratory, namely, for undergraduate or graduate work. Graduate schools prefer the larger module which permits larger individual research rooms. This decision, however, usually means two separate or adjoining buildings, one for the graduate school and the other for undergraduate work.

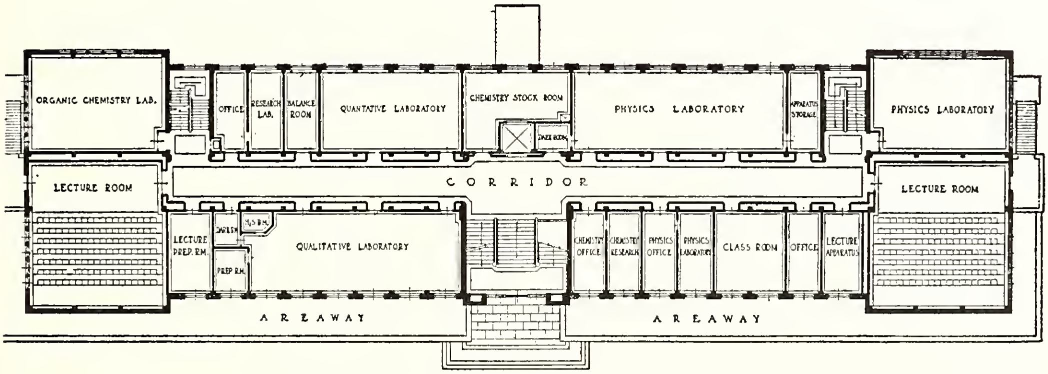
The module in the Kettering Science Laboratory (figures II.2.a, 2.b and 2.c) was determined by the spacing and size of the standard chemical locker table; namely, 4'0" by 12'0" feet of working space, or 4'0" by 13'6" including the end sink. The aisle between the locker tables is 5 feet 6 inches wide which results in a 9-foot 6-inch bay. Laboratory furniture companies now recommend a table 54 inches wide, which results in a 10-foot bay. Aisle widths of less than 4 feet 6 inches are not practical.

A room depth of 21 to 22 feet appears to be ideal, for



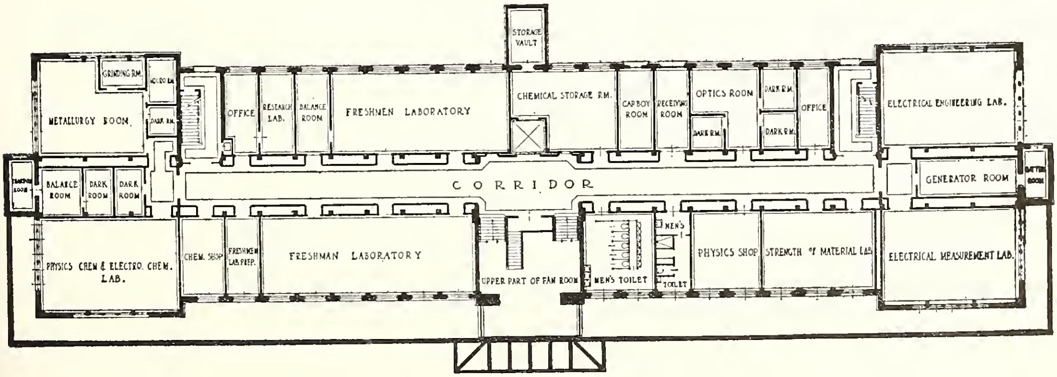
SECOND FLOOR PLAN

c



FIRST FLOOR PLAN

b



BASEMENT PLAN

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Figure 11.2 Floor plans of the Kettering Science Building at Antioch College.

it permits hoods or reagent shelves along the corridor or outer walls and leaves ample space at the ends of locker tables for freedom of movement on the part of students and instructors. The ends of the locker tables are opposite the columns so that light from the windows illuminates the aisles between the tables.

The resulting 9'0" to 10'0" by 21'0" to 22'0" foot module also gives reasonably good proportions when taken singly or in multiples, for offices, private laboratories, class rooms, rest rooms, etc. It is also structurally acceptable and permits the architect some latitude in the exterior treatment.

It is the concensus of opinion of most laboratory furniture companies that the best arrangement of chemistry tables, (i.e., the double-faced, center-trough type of table) is such that the sink-end of the table face the corridor wall. The opposite end may or may not extend all the way to the outside wall. The reason for this arrangement is that the sink end of the table is closer to the main service lines which are best distributed either in hollow corridor walls or run exposed on or concealed behind a false corridor ceiling. This same consideration also applies to hoods which may be located on the room side of the corridor wall.

Flexibility: Well-planned laboratories with flexible interior arrangements and also designed to permit additions to the building can be adapted over a long period of time to the growth and changes within a department. However, if the laboratory is planned only for the immediate teaching problem, fixed in plan and subdivision, the space soon becomes frozen, the building prematurely becomes obsolete and its conversion at great expense to other purposes on the campus is inevitable. Many colleges and universities have suffered from this dilemma, aggravated, to be sure, by the recent unexpected increase in enrollment as the result of the G. I. Bill.

Aids to flexibility include such items as simplicity of floor plans, adoption of a functional module and its free use in the floor plans, non-supporting interior walls which can easily be installed or removed, accessibility of all plumbing and other services, provision for services to be made available to each laboratory unit when needed, and types of hoods and fume ducts that are light, effective and flexible and permit their later installation or removal. Removable laboratory wall or center tables in research laboratories enables the teacher to adapt the room services to a particular problem.

Some standardization of laboratory furniture is an aid to flexibility. Industry has learned this trick but in general, college and university laboratory furniture tends to be a composite of the personal preferences of the individual staff members.

Accessibility of services in the Kettering Science Laboratory was accomplished by the simple expedient of hollow corridor walls (figure II.2.a). The doors opening on the corridor of the long rectangular building are spaced on the several floors so that the hollow walls are continuous from a plenum tunnel beneath the basement corridor to the attic space. All vertical heating, ventilating, fume ducts, plumbing and electric and other service lines in the building are concealed within these walls, but are easily reached at any point by the removal of one or more bolted panels of asbestos board, which constitute the corridor walls. These hollow walls are designed to permit horizontal distribution of service lines from one end of the building to the other. Repairing, removing, or adding new services is thus facilitated.

Flexibility in the distribution of services was accomplished in the new Firestone research laboratory by a completely free pipe shaft at every 24 feet along the center of the building. A special column arrangement was required to keep the shaft free of supporting steel. Where normally there should be one single column, there are actually four separate ones, one at each corner of a space measuring 4'0" by 6'0". One side of this rectangle is closed by a large vent shaft for air conditioning, but service lines can feed out in the other three directions.

The use of non-supporting screen walls to separate rooms is important in construction of the modern laboratory. This is easily accomplished by utilizing completely fabricated steel walls and partitions with fully demountable and interchangeable panel units, so that changes can be made easily and economically.

Where changes in room sizes or functions are not made too frequently, the employment of tile, or gypsum block covered with plaster, is useful. The architect can suggest other ways to accomplish this objective.

Functional Inter-relationship of Rooms: One of the most important basic planning principle in the design of any building is to obtain that overall arrangement and inter-relationship of rooms which gives the best functional operation in fulfilling the purposes of the laboratory. This involves a study of the overall traffic problem, which in turn helps to locate lecture rooms, class rooms, library, the larger laboratories, etc. It involves a study of the location and inter-relationship of that assembly of rooms, working as a unit within a department, which best carries out its particular function. Also the committee should attempt in its planning of the interior arrangement to eliminate waste cubage throughout the building, and have a regard for the subsequent maintenance and housekeeping considerations.

INTERIOR ARRANGEMENTS IN GENERAL SCIENCE LABORATORIES

For colleges and even the smaller universities the science building, housing two or more sciences, has many advantages. It keeps the science faculty living in daily communication with each other, allows for the advantages of a centralized science library, so necessary if research is contemplated, permits better integration in the liberal arts program, justifies one or more large lecture rooms and possibly an auditorium, and results in more efficient utilization of room facilities and more economical operation and maintenance.

There was a time when it was advisable for small colleges to house the chemistry department in a separate building because of the chemical fume problem, but modern ventilating equipment and properly designed fume exhaust systems take care of this problem satisfactorily.

The three-story science building appears to be the prevailing type. Some are planned to house only the physical sciences, others the biological sciences, while others involve various combinations of these. In general, the more sciences housed in a building the more difficult it is to design a building which permits the greatest freedom in flexibility.

The school's choice of the particular sciences to be housed involves too many special considerations to be profitably discussed in this report. To generalize our problem we will assume the building is to house the four major sciences of physics, chemistry, biology and geology.

Some of the factors which should be considered in arranging the various sciences in the building are as follows: 1. A consideration of the number of students handled by each department. On this basis, that department handling the most students should occupy some part of the first or first and second floors, thus save the energies of the students and help to reduce the maintenance cost of the building. In many colleges the chemistry department handles the largest number of students and should, therefore, be located on a lower floor. 2. A consideration of the location based on giving the best functional operation of the department in terms of its service facilities, such as plumbing, electrical, ventilation and fume-hood services. Since a common weakness in many laboratory buildings is a poorly designed and engineered fume-hood and exhaust system, a location for the working laboratories that will improve this situation should be carefully considered. In general this decision would place the chemistry department on the top floor, for it would simplify the exhaust system, shorten the risers, increase the system's general efficiency and be less expensive in installation and maintenance.

Disadvantages of this location include less stability for certain analytical operations, and longer drainage, plumbing, and electrical services which increase installation and maintenance costs.

It appears logical, on a functional basis, that the physics department should be located at or near the ground level. Many operations and measurements in physics require facilities free from vibrations which can best be obtained on a ground floor.

There are good reasons for placing the biology department over the chemistry department. The service lines and fume hoods required by biological laboratories are similar to those used by chemical laboratories. An installation economy is effected by concentrating these on one side of the building. (See figures II.2.a, 2.b, and 2.c, *Kettering Science Building.*)

For similar reasons the geology department can be placed over the physics department.

The reader will think of many alternatives to the above discussion which may be more logical in the given case than that suggested above.

INTERIOR ARRANGEMENTS IN THE UNIVERSITY CHEMICAL LABORATORY

Few of the large universities have a free choice in planning the type of laboratory which best suits their problem. The university campus is usually completely surrounded by business or residential districts which prevents its natural expansion. Growth and expansion over the years has resulted in a congested campus, higher buildings, and little choice of location with respect to the changing technological relationships to other buildings on the campus. Planning committees for new university laboratories or additions to old ones have had no alternative but to decide on a series of compromises far removed from an ideal solution of their problem. It would be futile and beyond the scope of this report to attempt to analyze these special problems. We will confine our discussion, therefore, to a few general observations.

The large university must plan for an ever-growing demand for research facilities in the graduate school as well as unforeseen demands (such as resulted from the G. I. Bill) in the undergraduate school. Most large universities would like to be relieved of the undergraduate problem, i.e., let the smaller colleges handle this as their specialty, and let the university concentrate on the graduate school. The higher percentage productivity in the smaller colleges of B. S. students who later become Ph.D.s in science suggests that this trend may be desirable.

In planning university chemical laboratories there appear to be two schools of thought. One school believes in separating the undergraduate laboratories from the graduate laboratories, locating them either in separate parts of the same building or in adjoining buildings. In fact the freshmen chemistry program alone in a number of our larger universities has justified one or more separate buildings.

The other school of thought attempts to integrate the facilities and laboratories for both the undergraduate and graduate work, believing that such integration has important educative values. The undergraduate students have an opportunity of living in the same environment with and watching their more advanced brethren in the graduate school in action.

Although the writer tends to be sympathetic toward the educational objectives of the latter, the planning problems are more complicated and invariably lead to greater difficulty in attaining that desirable feature of modern laboratories, *flexibility*. The graduate laboratory building problem is in general different from the undergraduate problem, usually requiring a different module of construction, special laboratory facilities, and greater need for flexibility in internal arrangements to meet the changing needs of research problems. Undergraduate laboratories on the other hand may be more standardized to meet their special production problems.

Whether one or the other of the above plans is followed, certain general considerations for planning laboratories can be suggested for the larger universities: 1. As long as the traditional departmental subdivisions of chemistry into inorganic, analytical, organic and physical are retained as functional units in the teaching of chemistry we should plan both the graduate and undergraduate laboratories around these subdivisions. In the multi-story graduate school laboratory each subdivision can be so organized as to occupy, as a first approximation, a floor of the building. The subdivision will have its own compliment of rooms such as offices, class rooms, research laboratories, stock room, etc. It should be a reasonably sufficient and independent working unit.

In the one-story undergraduate laboratory all these subdivisions will be on the ground level. However, they can still be organized to occupy their own particular section of the building. The preference of location might be based on population of the subdivisions, functional and administrative problems, accessibility to exits and avoidance of congestions in corridors during change of classes.

2. In the event that a multi-story laboratory is indicated for the undergraduate school then it is the writer's feeling that the general chemistry laboratories should be located on the lower floor or floors. Analytical, organic and physical chemistry may be located on the upper floors depending on the personal preferences of the staff. Certain physical measurements in physical chemistry may require basement facilities.

3. Chemical engineering laboratories, if located in the university laboratory building, should occupy a wing of the building. Since many of the operations in chemical engineering laboratories are quite distinct from those in ordinary chemistry, requiring ceiling heights equivalent to two or three floors, special building construction problems are introduced. A separate building housing chemical engineering might be seriously considered since every special construction problem introduced into a university laboratory increases the difficulty of designing a laboratory that lends itself to flexibility.

The Lecture Room

The preferred location of the large lecture room or rooms is such as to make easy access to these rooms from the main entrances to the building. See figure II.2.b. In general, this location will be the first or ground floor of the building.

Some of the reasons justifying this location are: 1. most of the students who enter lecture rooms come to the building for this purpose only and leave the building after the class is over; 2. the lecture room is frequently used in the evenings by students and faculty for science and chemistry club meetings, special lectures by the staff or by outside lecturers; 3. in this day and age of large enrollments the class and lecture room facilities of most colleges and universities are used freely by departments other than science.

Many factors enter into the decision of the size of lecture rooms: 1. The normal or anticipated lecture room population may be used as a guide which in most colleges and universities is determined by the freshmen chemistry enrollment. 2. If the enrollment or other factors permit, particularly in general science buildings, two or more smaller lecture rooms may be preferred to one large one. This decision should be carefully considered by the planning committee. Frequently these smaller lecture rooms can be housed on one floor with seat risers. Such one-floor lecture rooms save cubage, simplify building construction and add to the general flexibility and utility of the building. With careful planning they will seat from 150 to 200 students. 3. Seating capacities of 200 or more usually indicate a lecture room involving a ceiling equivalent to two or more floors. This in turn introduces special construction problems and may necessitate a special wing of the building. Lecture rooms seating 375 or more should include a balcony. It is not practical or desirable even in large universities to have lecture rooms seating more than 500 students. The distance from the lecture table to the farthest seat should not exceed 55 to 60 feet. The floor area in square feet required for a given seating capacity may be calculated roughly by multiplying the seating capacity by ten.

The fixed pedestal-type tablet arm chair permanently anchored to the floor is best for lecture rooms. The chairs should be arranged with the aisles running front-to-back of the room and so spaced in rows as to allow free passage way cross-wise of the room.

Planning committees will have their own preferences about the size, design and service equipment of the lecture table and other accessories in the room such as projection equipment, galvanometer scales, etc., so only a brief observation will be made. In some universities the lecture demonstrations are brought into the lecture room on a movable table which runs on a track leading from the lecture preparation room. This table then becomes an integral part of the lecture or demonstration table and often obviates the necessity of subsequently changing the assembled apparatus to other parts of the tabletop. Service lines to this movable section are then connected through flexible rubber tubing, etc. to the permanent service supplies in the room. It is the writer's opinion, after interviewing the chemical faculty in several universities where this arrangement is followed, that it has not proven too practical. A large table, approximately 3' by 8', mounted on rubber tired casters or wheels, which may or may not form an integral section of the lecture table, is to be preferred.

The lecture preparation room should be located as close to the lecture room as possible. It may be placed 1, under the elevated seats of the lecture room, 2, the first room outside the lecture room bordering on a corridor, or 3, preferably a room back of the wall separating it from the lecture table. In the event the latter is adopted, a hood may be built into the wall back of the demonstration table so that it serves both the lecture room and the demonstration room, and thus obviates the necessity of a down draft hood mounted on the lecture table of chemical lecture rooms.

The front and side walls of the lecture room should be kept as free as possible, not only for an ample blackboard, but for the use of a screen, charts, pictures of scientists and other forms of visual education. Of course, the acoustics of the lecture room must be considered carefully.

Class Rooms

An ample supply of class rooms is a necessity in any laboratory building. These should be located judiciously throughout the building to serve the various sciences housed or the various departments of a given science.

The seating capacity of such rooms varies from 25 to 50. The seats may be movable or fixed. A small lecture table suitable for demonstrating simple experiments is desirable. As much as possible of the available walls should be covered with blackboards.

Offices and Private Research Laboratories

The adoption of a building module of *approximately* 10'0" by 22'0" results in reasonably convenient offices and adjoining private research laboratories. Such offices give ample space for a desk, a small wall blackboard, book shelves for a private library, filing cabinets, and small wall cabinets.

In some recently designed laboratories no provision was made for private research laboratories. This policy, in the writer's opinion, is a mistake unless the limitation of funds left the planning committee with no other alternative. The older faculty members in many of our smaller colleges, burdened by teaching loads over the years, have not had the opportunity to develop the research habit, but there is evidence that this situation is changing. Many of our young prospective teachers are now insisting that they be provided with facilities for carrying on research.

Stock Rooms

In general science buildings one or more stock rooms may be necessary to service each of the various sciences housed. A general stock room serving all of the sciences in a general science building is not desirable since its location is not sufficiently accessible to the various laboratories. Also the storage of chemicals in the same room with many expensive physical measuring instruments is not recommended. However, in small colleges a centralized stock room may be a reasonable compromise when the overhead involved in maintaining a stock room attendant is considered.

In most large university chemical laboratories a stock room supplying both chemicals and apparatus is located centrally with respect to the laboratories associated with each of the departments of general, analytical, organic, and physical chemistry, and chemical engineering.

A similar set of stock rooms should be distributed among the graduate laboratories if these are housed in a separate wing of the building.

In some large school laboratories special stock rooms are provided for the storage of acids and ammonium hydroxide in bottles or carboys.

Associated with a chemical stock room is usually a room designed to house flammable or explosive chemicals. This room is frequently built as a separate addition to the outside of the building and placed below ground if its appearance is objectionable. The room may be supplied with a floating roof designed to give way in the event of an explosion. It should also be supplied with automatic fire protection.

In large universities where large quantities of flammable or explosive chemicals are purchased it is desirable to store them in isolated buildings on the campus, bringing to the service stock rooms only such quantities as are required daily or weekly.

Another type of stock room is recommended for graduate laboratories, particularly in large universities. It stores floating equipment such as vacuum pumps, microscopes, electrical measuring meters and instruments, etc. An attendant with mechanical ability can use his spare time repairing faulty apparatus. A card file noting the location and use of such equipment among graduate students or faculty, helps to maintain its efficient use.

Also planning committees should anticipate the need of ample storage space for used equipment which will free laboratories of accumulations, save headaches, and conserve the nervous energies of teachers for more creative work. In larger universities such storage space may be under the supervision of the attendant mentioned above.

Science or Chemical Library

Scientists constantly depend on ample library facilities, especially in schools where research is encouraged. These facilities should be easily accessible and consequently should be located in the laboratory building. There is pressure on the part of the administrations of some of our smaller colleges to combine science libraries with the main college library in a separate building, often quite remote from the science laboratories. This attitude cannot be defended and stems from an ignorance on the part of the administration as to how teaching and research scientists operate.

In many prewar college and university laboratories the science library space has become frozen and inadequate to accommodate the rapidly expanding literature. As a result stack room space is slowly encroaching on the available space in the reading rooms. Planning committees should give careful consideration to this problem. The advice of competent science librarians should be considered.

Museum or Display Cases

Provision in modern science laboratories should be made for exhibits of chemicals, models of chemical and physical industrial operations, new and historic apparatus and many other displays of educational value to science students as well as liberal arts students and visitors who frequent the building. There are various ways of handling this problem such as providing a special room reserved for the purpose, the use of removable show cases lining the corridor walls, if the corridor is wide enough to permit, or show cases with sliding glass panels may be permanently built into hollow corridor walls. These may project out an inch or so. A depth of 8 to 10 inches can usually be employed for such cases without interfering with the primary function of the pipe shaft behind the cases. Proper lighting effects are essential.

If corridor walls are used for this purpose, the corridor leading to the lecture room or rooms will experience the most traffic and therefore be the best location for such displays.

Special Rooms

The teaching of modern science has become so specialized, particularly in the graduate schools, that many special rooms are required to carry on the work successfully, economically, and with the least waste of time. Planning committees should consider rooms designed for constant temperature, rooms for low temperature, rooms for controlled humidity, isolated and carefully insulated rooms for radioactive isotopes and tracer chemistry, x-ray rooms, air-conditioned dark rooms for spectroscopic studies, vibration-free rooms for infrared work, and dark rooms for the electron microscope, ultramicroscope, etc. Colloid chemistry with its ultra-centrifuge requires a special room with proper protection to the operators.

Courses in instrumentation frequently require rooms for wood and metal working, glass blowing, etc., in addition to rooms for the professional machinist or glass blower required in most graduate laboratories.

Room should be provided in graduate laboratories where the graduate student can have his desk and assemble his growing private library. It is not always possible or desirable for the graduate student to have his desk in his working laboratory. One or more large rooms supplied with desks are frequently reserved for the first or second year graduate students. Smaller rooms with one or two desks are reserved for the more advanced students.

Various conference rooms should be provided not only for meetings of the staff, alone or with graduate students, but rooms where graduate students may be interviewed in private by prospective employers. Private industry and government laboratories are working more closely than ever with graduate and technical schools and this excellent practice promises to grow and continue in the future.

The many other service rooms housing storage batteries, transfer panels, motor generator sets, distilled water supply, etc. will be apparent to planning committees. The advice of trained experts in these respective fields should be obtained. In communities where the water supply is hard, a considerable amount of trouble may be experienced by the residue which collects in the still and condenser jacket during the preparation of distilled water. At Antioch this situation was corrected by storing rain water, collected from the slate roof, in a large cistern buried in the ground outside of the building. This cistern is fitted with a filtering wall to remove any sediment. The cistern water is then pumped through a pressure tank located in the basement to a steam heated automatic still located in the attic space, where part of the water is boiled and condensed to produce the distilled water, the other part serves to cool the condenser jacket and is then returned to the cistern.

Corridors and Stair-wells

Planning committees should give careful consideration to the width and treatment of corridors and stair-wells. All too frequently corridors and stair-wells are made too narrow (8 feet or less) to take care of the normal or emergency traffic. If narrow corridors are also used for the horizontal distribution of services, (run exposed or above a false ceiling) the resulting corridors become practically tunnels, are depressing and detract from the general atmosphere of the building. Corridors 10 feet wide or wider are usually required to handle the traffic to and from lecture rooms or an auditorium. Narrow stair-wells are not only a building hazard in the case of fire but do not permit the architect much latitude in treatment. The proper treatment of both corridors and stair-wells can change an otherwise cold, drab, barn-like laboratory building into one that both the faculty and students can work and move around in with a feeling of comfort.

The writer realizes that the above treatment is sketchy, but if it has called attention to some significant items of interior planning and arrangement, it may help planning committees to approach their problem more objectively. Perhaps some day we can have that laboratory designed to provide every possible facility, every safeguard to equipment and personnel, every possible aid to flexibility, and every possible provision against premature obsolescence—in a building devoted to teaching students how to make things obsolete.

The writer wishes to thank the many schools who submitted floor plans, pictures and suggestions and the various architects and furniture supply companies for their cooperation in supplying information for this part of the report. The writer regrets that the limitations of space prevents giving proper credit to all these sources.

3

THE GENERAL SCIENCE BUILDING

W. A. Manuel Ohio Wesleyan University, Delaware, Ohio

A survey of college campuses would show that the larger chemistry departments usually have their own buildings, while the smaller departments are frequently housed in general science buildings. If new quarters for the department of chemistry are contemplated on a given campus, two questions should be raised. What are the advantages and disadvantages of housing chemistry in a general science building? Everything considered, should chemistry have a separate building on this particular campus?

This chapter is concerned with general principles which may throw some light on these questions but does not discuss details of construction because they are adequately treated elsewhere in this volume.

In buildings which house the department of chemistry and one or more other sciences, we find two extremes of practice. At one extreme is the building in which chemistry is a completely separate unit even though the dividing line between its space and that of other departments is an imaginary one. At the other extreme is the building in which there has been a deliberate attempt to share as many facilities and to pool as much equipment as possible. The more recent trend seems to be toward the latter type of building.

If the department of chemistry is to be housed as a separate unit in a general science building, it will be desirable to plan the building and divide the space in such a way that the department of chemistry will not be handicapped by the proximity and activities of other departments. Neither should the department of chemistry itself be a hazard to other departments in the same building.

In some such buildings space is divided horizontally and chemistry occupies one or more floors. It does not seem to matter too much whether chemistry is above or below other departments in the building. Modern ventilating systems provide fans to bring in fresh air and draw out bad air and obnoxious vapors. The result is that any floor, above or below a chemical laboratory, can be protected from fumes. However, chemical laboratories that are located above other departments may require plumbing and other service lines to go down through "alien territory" which may constitute a hazard to such departments. Short supply and waste lines also give much less trouble than long ones.

In science buildings where the division of space is vertical rather than horizontal, the department of chemistry will perhaps occupy a wing of a building. Just which wing is best suited for chemistry, and just how many floors there should be, are questions which must be answered individually campus by campus.

Planning New Quarters for Chemistry

The decision to build should not be made hastily. Adequate time and consideration should be given to an exploration of every one of the various possibilities. It is recognized that sometimes the available funds come

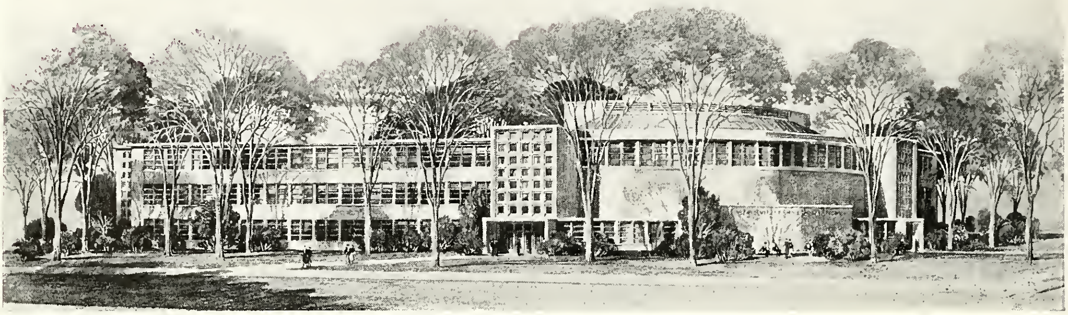


Figure II.3 Science Building at Wayne University, Ralph R. Calder, Architect

from donors who have definitely specified a building of a certain type or for a certain purpose. Since gifts frequently are made at the solicitation and under the guidance of a college official, it is highly desirable that the college administration know what is best suited for the needs of all concerned. In the case of a new science building or new quarters for chemistry, for example, it would be well for the chemistry and other science departments to make a careful study with the administration before a commitment is made.

Important Considerations

Factors to be evaluated in choosing between a general science building and a separate chemistry building fall into four categories: cost of construction, cost of maintenance, educational efficiency, and miscellaneous local problems.

Cost of Construction

Will it cost more to provide the required amount of space for the department of chemistry in a general science building or in a separate chemistry building? Although for certain industrial purposes it is cheaper to construct a single-story building with a given amount of space than it is to build a multi-story building, this is not necessarily true of a science building; the specific local situation must be studied by the architect, the planning board and others concerned.

From his preliminary plans the architect should be able to make reliable estimates of the relative costs of the various buildings. Costs should be reported and compared in terms of cost per unit of usable space rather than in terms of cost per unit of total space because one plan may require more halls, stairs, and other service areas than another.

Cost of Maintenance

Whether quarters for chemistry may be maintained more cheaply in a separate building than in a general science building depends upon local conditions. The only safe procedure is to make an estimate based on experience. Maintenance cost data for existing buildings should be available from the business office and it should be possible to extrapolate these data to the proposed buildings with some degree of accuracy.

Some of the larger universities have found that, in general, it costs more, per unit of usable space, to maintain a small building than a large building of the same type. Each school, however, should investigate its own costs.

Educational Efficiency

The dean of the college and the members of the science departments are more concerned with educational procedures than are the architect and the financial officers. They should, therefore, be consulted about the plans in relation to educational efficiency and should prepare a report for the use of the planning committee. This report should take precedence, as often as possible, over the wishes of the donor or the artistic ambitions of the architect. A science building should be planned primarily as an educational tool rather than as a memorial or as an example of imposing architecture.

The important question in connection with a choice between a separate building for chemistry and a general science building is, which will yield the higher educational dividend?

Those who favor a general science building will call attention to many possible advantages, among which the following may be listed:

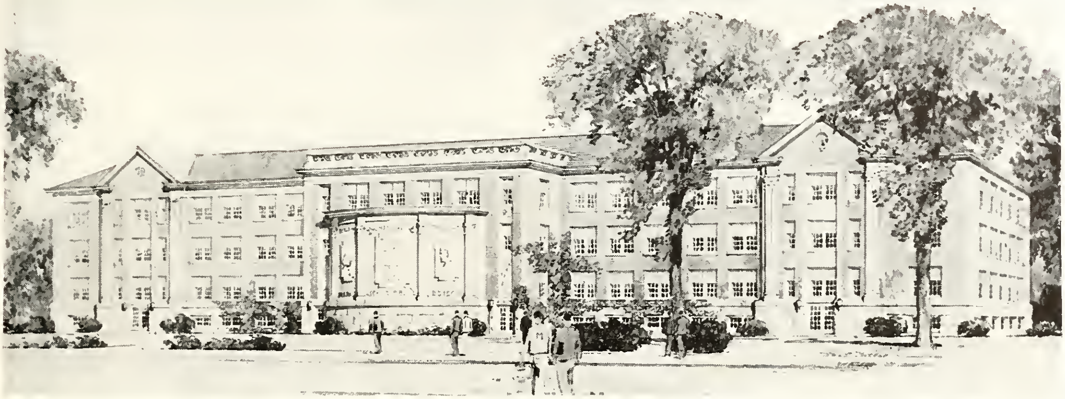
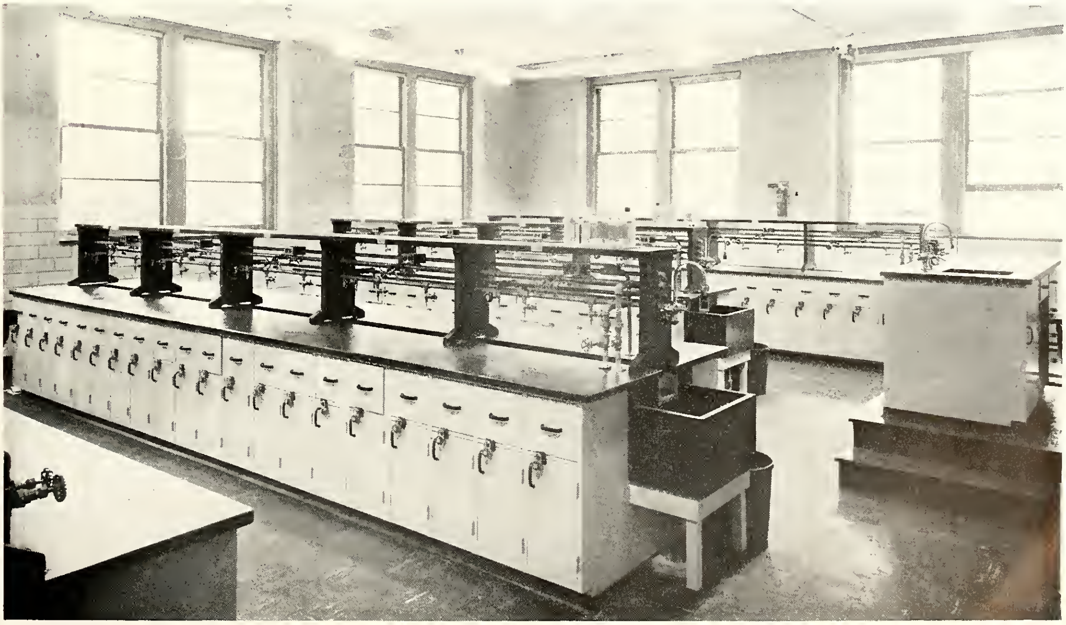


Figure 11.4 Science Hall of Marshall College, Huntington, West Virginia. Architect: L. D. Schmidt.

A. The housing of several sciences in one building should result in greater cooperation between the sciences thus tending to broaden a student's interests and outlook. Many educators are convinced that there is now too much and too early specialization in the training of scientists. All too frequently a chemist knows so little about other sciences that he fails to recognize the potentialities of a broad attack on a problem. While the mere housing of separate departments in the same building will not necessarily mean greater cooperation between departments, it should make cooperation easier and more natural.

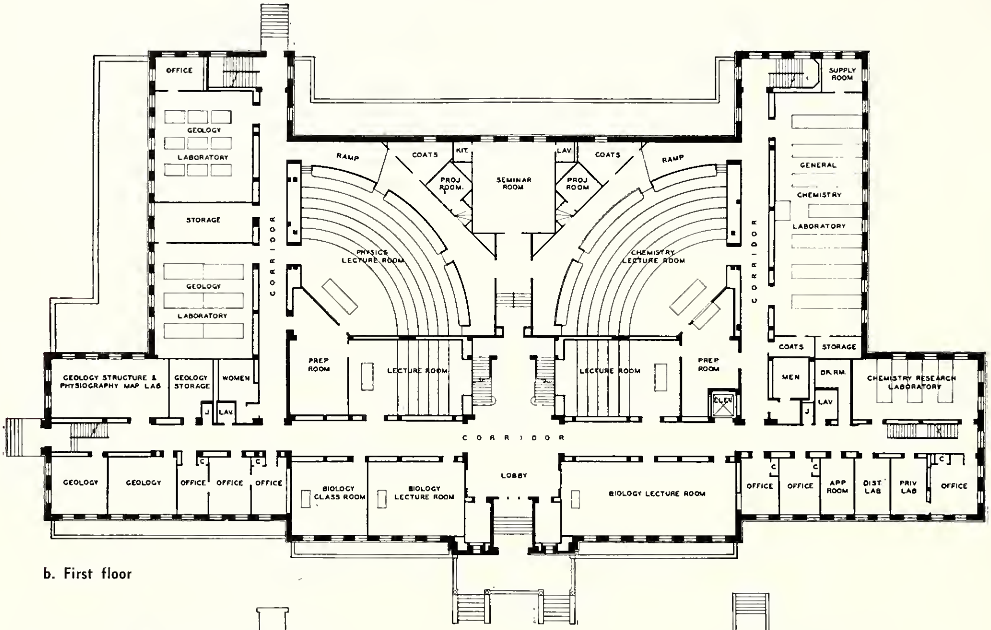
B. Some degree of economy may be effected by the joint use of facilities if two or more sciences share the

Figure 11.5 Interior view of the General Pharmacy Laboratory of the University of Michigan.

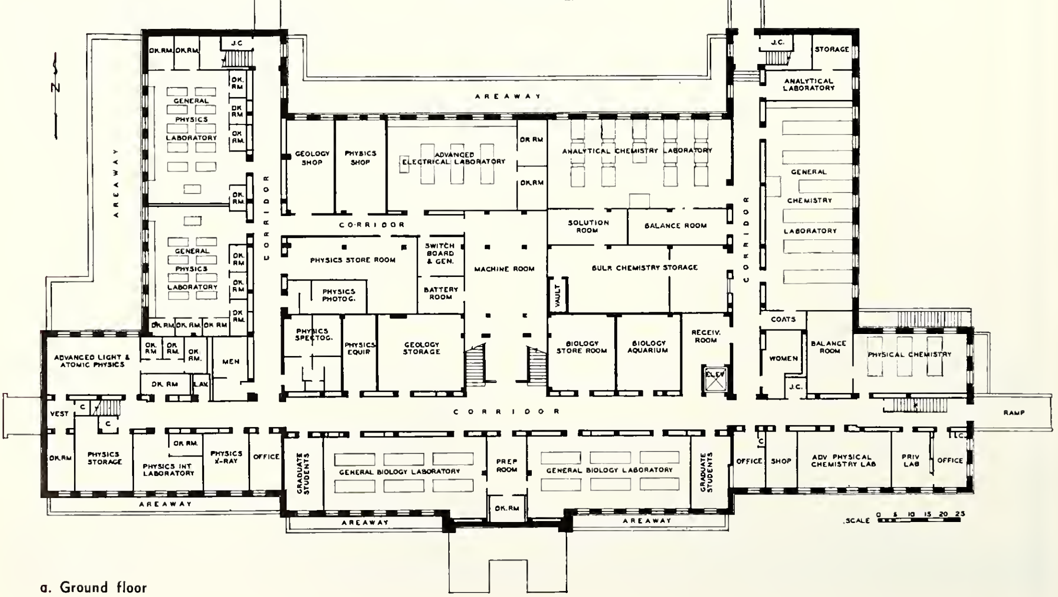


same building. Under such a housing plan it should be possible to have a greater variety of class and lecture rooms than would be practical in separate buildings. Furthermore, by proper cooperation in schedule making, a smaller number of rooms should suffice for the needs of all, and each room would be used a greater number of hours per week.

In a general science building one might justify a small auditorium, larger than actually needed for most classes. Such a room could be used for inter-departmental lectures, scientific meetings, and other public events too large for a class room and too small for a large auditorium. It would be possible, in planning the general science building, to group other lecture rooms around the auditorium in such fashion that almost any of the visual aids, demonstration equipment and lecture

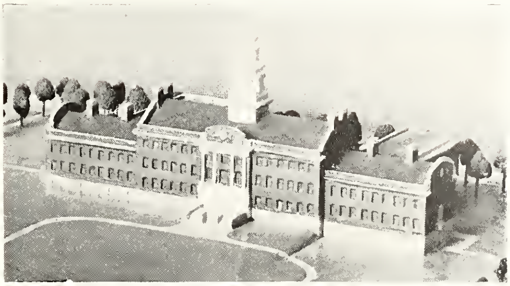


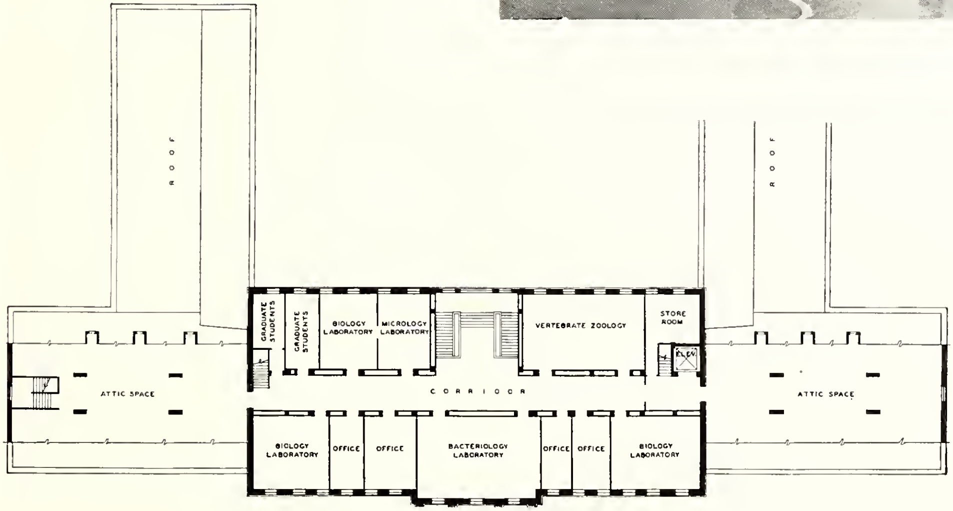
b. First floor



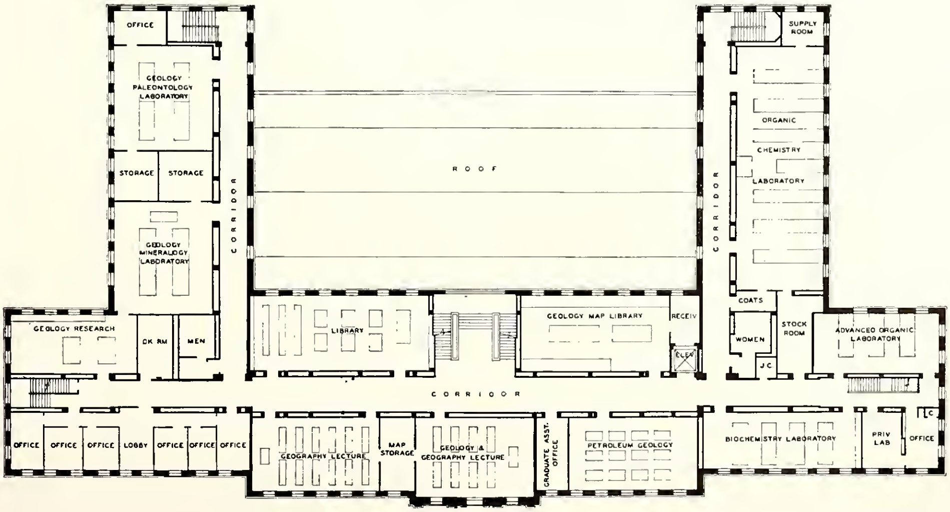
a. Ground floor

Figure II.6 and 7 Floor plans and model of the Fondren Science Building at Southern Methodist University, Dallas, Texas.





d. Third floor



c. Second floor

preparation facilities in the auditorium could be used in any of the lecture rooms.

Among other facilities which might be shared are these: the library, with separate alcoves for each science, but only one card catalog and loan desk; seminar rooms adjacent to the library; a receiving room and general stock room, stocks from which would supply sub-stock rooms serving individual laboratories; mimeographing and duplicating room; carpenter and machine shop; drawing room; the source of distilled water; photographic dark room, including individual dark rooms for instruments. In addition there might be one receiving or waiting room with centralized offices and a dictation room.

C. Friendly cooperation might enable the pooling of some of the more expensive pieces of equipment to serve all departments, thus making it possible to have a greater variety of equipment available because of the decreased necessity of duplication. Among the many possibilities that come to mind immediately are microscopes, spectroscopes, cameras, enlarging machines, electrical instruments and balances as pieces of equipment that might be shared. The first tendency will be to feel that such cooperative use of facilities and equipment is either impossible or, at best, highly impractical. Among other things, departmental ambitions may stand in the way. An open-minded approach, however, should result in the finding of a substantial list of equipment and facilities which could be shared without any real handicap and perhaps with mutual benefit. Such cooperation might even help break down any existing inter-departmental barriers to the advantage of all concerned—particularly to the advantage of science students. After all, it should be realized that cooperation among departments is neither more difficult nor less desirable than cooperation within a department.

The proponents of a separate building for chemistry will list such arguments as the following:

A. A separate building for chemistry could result in a more functional type of building. Construction materials and types of finish suitable for a chemistry building are different from those best suited for other sciences. A separate chemistry building may permit greater freedom in planning and a better choice of materials.

B. A better departmental esprit de corps may be built if chemistry is housed in a separate building.

C. Fire, flood and fume hazards, inherent in a chemical laboratory, will not endanger other departments if chemistry is housed separately.

D. Service lines for electricity, gas, heat, sewage and ventilation, so important in a chemical laboratory, may be installed and maintained more economically in a separate chemistry building.

Local Problems

Eventually, of course, purely local problems, peculiar to the campus concerned, must be considered in weighing the relative merits of a separate chemistry building against quarters for chemistry in a general science building. Among the important items to be considered are these: 1. general layout of the campus and the amount of ground available, 2. long-distance plans for campus development, 3. lines of traffic on the campus and relationship between buildings, 4. urgency of the needs of chemistry as compared with those of other sciences to be housed, 5. availability of funds and possibilities of raising funds for one or the other project, and 6. the degree of cooperation among departments which can be obtained now and later.

Other possible advantages and disadvantages of each plan will be apparent when studies are made. Before either the chemistry department or the administration has made a commitment as to which plan is more desirable, all departments concerned should meet with the proper administrative officers and the architect to plan a survey of the existing situation and needs. Every factor should be given careful and unbiased consideration, and the plan adopted should be the one that promises most for the attainment of the over-all objectives of the college.

4

THE GENERAL CHEMISTRY LABORATORY

John C. Bailar, Jr. University of Illinois, Urbana, Illinois

The rapid growth of college enrollments and the ever-increasing emphasis on science and technology during the past two decades have put a great burden on the laboratory sciences and have brought about many changes in instructional methods and equipment. Changes have been most pronounced in general chemistry where the introduction of smaller lockers and simpler equipment has doubled, and in some cases tripled, laboratory capacity. Part of this increase in efficiency has been brought about by the use of semimicro methods, but more than half of it has been effected by removing the larger and less frequently used pieces of equipment from the student's locker. In the newer laboratories the tripod, the ring-stand and the funnel rack are usually kept in an unlocked cupboard so that six or eight students may use them during the course of the week. Pneumatic troughs and iron pans, seldom used at present, are handled in the same way. Bunsen burners are still individual equipment in most laboratories, but there seems to be no reason why they, too, cannot be used in common. All items which are neither readily broken nor likely to be stolen may well be handled in this way. In addition to saving the major portion of the investment in hardware, breakage in the student lockers is greatly reduced. At Washington State College ring stands have been mounted permanently (figure II.8) so that no provision need be made for storing them, a highly successful arrangement.

Little used pieces of equipment, such as U-tubes, combustion tubes and mortars, should not be placed in individual lockers but kept in the store room and issued on temporary loan when required. If the course is so organized that all students in a class do the same experiment on the same day, the storekeeper may bring the requisite number of pieces to the laboratory at the beginning of the laboratory period and collect them at its close. If the course is not so organized, each student may go to the storeroom when he is ready for the experiment in question.

This rather drastic reduction in the amount of equipment in the student locker makes it possible to eliminate the "drawer and cupboard" arrangement common in the laboratories for more advanced courses, and to give each student a single drawer, which may be 16" by 20" by 9" deep. A laboratory table unit containing nine such lockers on each side will be of standard height and about 5 feet long—quite adequate for work in gen-

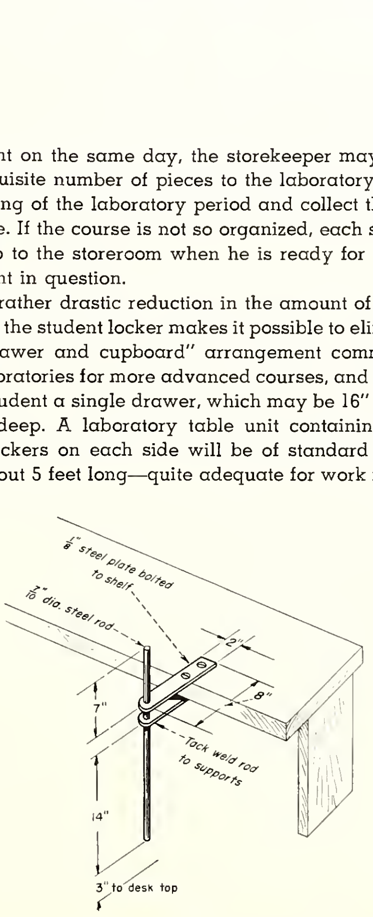


Figure II.8 Permanently mounted ring stand (Washington State College).

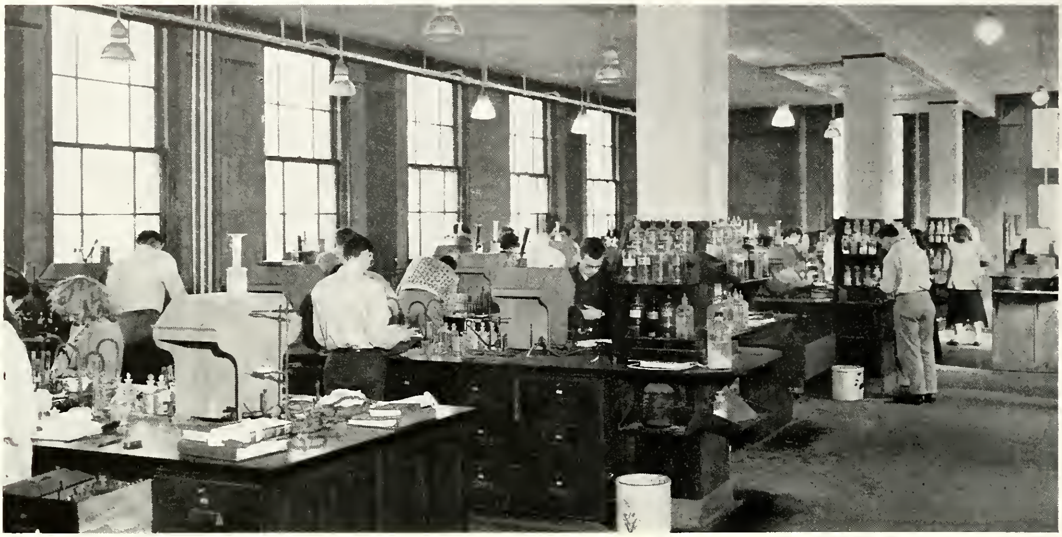


Figure II.9 Laboratory for General Chemistry, University of Illinois.

eral chemistry or qualitative analysis. Since it is difficult to schedule laboratory sections at nine different times during the week, some schools have replaced two or three of the individual drawers with a cupboard for equipment which is to be used in common. In other schools cupboards for common equipment have been placed beneath the sinks. The scheduling of nine laboratory classes during the week may be accomplished by making the periods two hours long or by having classes meet during the noon hour or in the evening. A typical installation (University of Illinois) is shown in figure II.9. Each table contains 54 lockers (27 on each side) and each working space is adjacent to a sink (indicated in the photograph by the goose-neck faucets). In this installation, no cupboard is provided for the common equipment so it is left on the tabletop. At the University of Wisconsin the drawers are somewhat narrower (about 10 inches) but each student is given two drawers, the upper one being 5 inches deep and the lower one, 9 inches. This allows ten students to use a single 5-foot working space during the week. The substitution of a trough for the sinks in the tables still further increases the capacity of this laboratory.

Northwestern University (figure II.10), unlike most of the other midwest universities, has retained the drawer and cupboard arrangement, the whole being enclosed behind a single door (figure II.11). This allows four lockers in a working space of 5 feet. The small drawer shown in figure II.11 extends almost to the other side of the table, leaving only enough room for a small cupboard which holds a box of weights.

In smaller colleges which use the same laboratory for general chemistry and for more advanced courses, the lockers are usually designed for use in quantitative analysis and organic chemistry. While this gives great flexibility in scheduling, it is wasteful of space in that it allows the beginning student more locker space than he really needs. A table unit containing a vertical tier of three drawers for general chemistry and two "drawer and cupboard" combinations for the advanced courses might offer a useful compromise.

Dunbar has described* portable lockers, kept in racks in the hall or in an open space in the laboratory, which the student places on his desk when he is ready

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* J. Chem. Education, 25, 35 (1948).

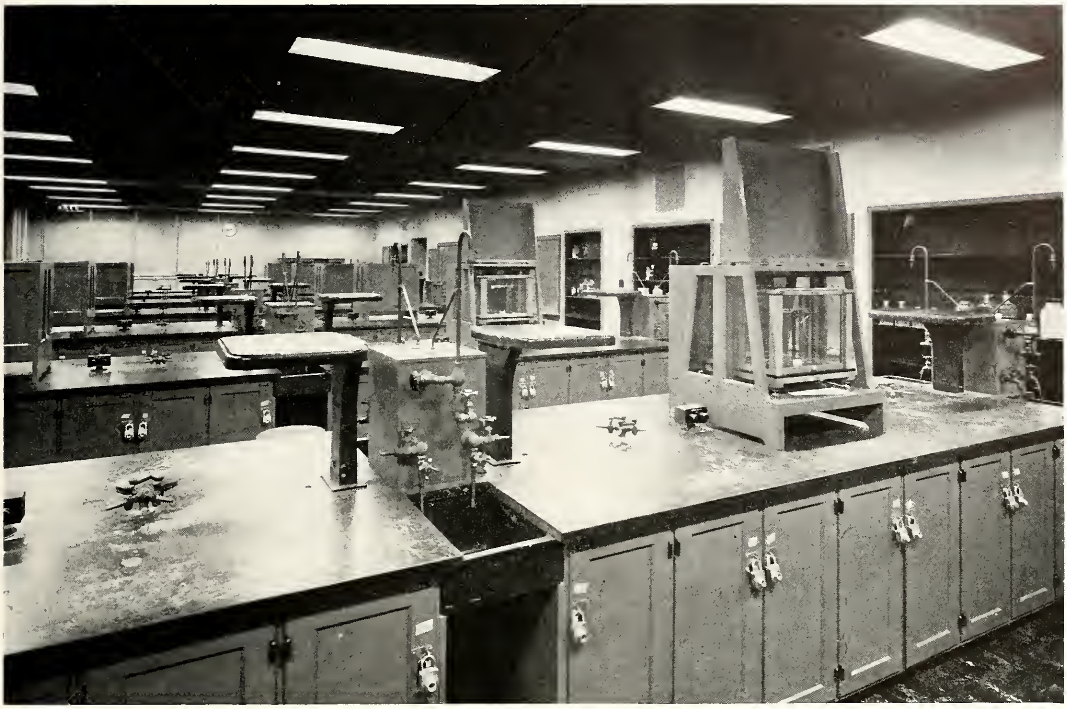

Figure II.10 Laboratory for General Chemistry, Northwestern University.

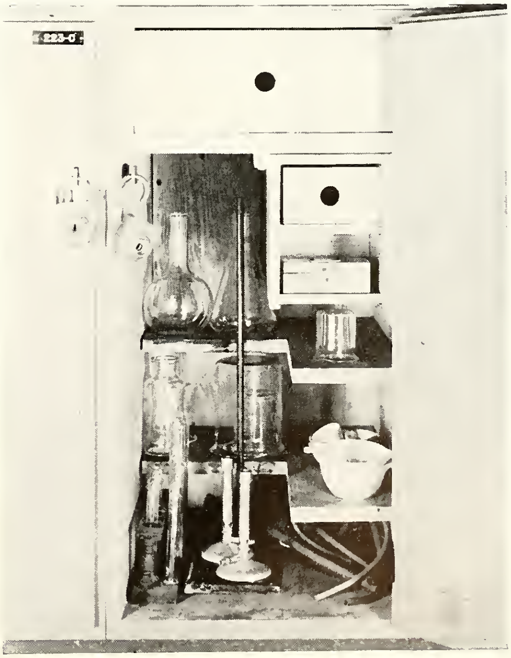

Figure II.11 Locker for General Chemistry Laboratory, Northwestern University.

to work. This arrangement has been used in a number of schools with the saving of a great deal of laboratory space. The moving of the boxes at the beginning and end of the period, however, causes a great deal of confusion and takes time from the laboratory period. This system is, at best, only a makeshift; it is much better to have a large number of lockers built into the laboratory tables.

The State Universities of Iowa and Ohio have recently designed rather novel laboratories which serve both as laboratory and classroom. The students all face the same direction and sit at their work. The instructor may stand on a podium at the front of the room where he can be seen readily by all members of the class while he lectures or performs laboratory demonstrations. The front wall of the room carries a blackboard, a periodic chart and any other wall charts that may be required. Proponents of this plan believe that the students become less fatigued and so do better work if they sit instead of stand. Undoubtedly it encourages more discussion and demonstration by the instructor and should thus give closer integration between the classroom and laboratory segments of the course.

LABORATORY SERVICES

There is much diversity of opinion as to what laboratory services are required for general chemistry and how these should be arranged. At the very minimum every student should have water and gas at his table. A double cock should be provided for gas as some experiments require two burners. Hot water is convenient for washing glassware but need not be piped to every desk. In a small laboratory one or two outlets are sufficient. Attempts to furnish hot water by mixing steam with tap water are usually unsuccessful because of fluctuations in pressure with consequent variations in the temperature of the water.

Distilled water is a necessity, but in the interests of economy it should be distributed from only one or two outlets in each laboratory. There should be a small sink under each outlet to catch the inevitable drip and spillage. Distilled water may safely be conducted through either block tin or aluminum, the latter being less expensive and easier to install.

Sinks. Opinion is divided as to whether it is necessary to have sinks placed in the laboratory tables so that each student is next to a sink or whether it is better to have a trough down the center of the table with a large sink at the end. Teachers of general chemistry, in general, seem to favor the plan of having a sink for each student. This saves many steps and allows the student to use the sink as a pneumatic trough. The additional sinks take space, however, so troughs should be used where space is an important factor.

Vacuum is required in the performance of a few experiments and some means of producing it should be available at every table. A central pump with pipes leading to each table is very convenient but is not justified in a small department where the pump would not be used frequently. Lacking such a system, aspirators attached to the water faucet serve the purpose quite well.

DC Electricity. For experiments in electrolysis and transference of ions, a source of low voltage direct current is required. Since these experiments constitute only a small portion of the course, it is doubtful whether the installation of DC at every student table can be justified although it is undoubtedly a great convenience. The installation of four or five DC outlets in each laboratory is, in general, satisfactory.

Hydrogen Sulfide. Methods of handling hydrogen sulfide have received much attention but there is still great diversity of opinion on the matter. Many teachers of qualitative analysis are using the semi-micro method and find it satisfactory to furnish each student with a test-tube size H_2S generator which he can use under a small hood at his table. If a larger installation is desired the gas is usually purchased in cylinders and dispensed through a reducing valve or an oil-sealed gasometer. In general, reducing valves have been found to be unsatisfactory, because of corrosion of the mechanism. The gas may be conducted through wrought iron, or preferably aluminum piping. If iron is used, the piping should be so arranged that it can be "rodded out" from time to time because some corrosion is bound to take place. This is especially important if the gas is "home" generated from iron sulfide and acid because such gas always contains acid fumes and moisture. The hydrogen sulfide cylinder or generator must be kept outside rather than in the building. Fatal accidents have occurred in several laboratories in spite of many precautions.

If there are individual hoods on each table the hydrogen sulfide may be piped directly into them (figure II.9). Otherwise it may be carried into a manifold with several outlets in a good hood which is centrally located in the laboratory. A great deal of confusion is avoided and time is saved if the hydrogen sulfide can be piped to each table. The initial cost is greater, of course, but the ultimate saving in student time will more than justify the initial expenditure.

Hoods. Laboratory hoods may be divided roughly into two classes: small, individual hoods which are placed directly on the laboratory table; and wall hoods which are usually large enough to accommodate an entire laboratory set-up. The individual hoods are to be preferred for general chemistry because they cut down the amount of traffic in the laboratory. It is, of course, more costly to install a large number of individual hoods than a few larger wall hoods, but in the long run this expense is justified. The hoods shown in figure II.9 are of aluminum alloy. A central duct inside of the table draws air through the three hoods on the table and down through the floor into a large "Transite" duct on the ceiling of the room below. (Such a duct may be seen on the ceiling in figure II.9.)

The Mathews hood was developed by J. H. Mathews of the University of Wisconsin and has proved to be very satisfactory.

This hood consists of a cast iron circular shell 18 inches in diameter and about 3 inches deep (with an opening at the top for connection to the duct), provided with a "bonnet" which projects forward from the vertically placed cast iron shell. The upper edge has a turned down "lip" which tends to keep light gases from escaping. Inside the shell there is a circular baffle plate so set as to provide a 3/16 inch circular slot through which air is drawn at high velocity (150 cubic feet per minute per hood). The high velocity makes this hood effective. A small volume of air traveling at high velocity is a more effective ventilation principle than a large volume of air traveling at low velocity. As the slot is circular and nearly 18 inches in diameter, both light gases and heavy gases are taken care of equally well if they are released under the hood.

The down-draft is impossible in the installation because of the trough in the middle of the tabletop.

If wall hoods are used they should be placed at frequent intervals around the room so that the students will not have to walk far to reach them. Traffic through the laboratory should be kept at a minimum at all times because it disturbs and distracts the class.

GENERAL ARRANGEMENT OF THE LABORATORY

It is commonly agreed that a general chemistry class should not exceed 24 students, so laboratories should be built to accommodate 24 or some multiple thereof. Larger laboratories give better utilization of floor space and, where much of the laboratory supervision is handled by inexperienced teachers, there is some advantage in having three or four classes in the laboratory together. One of the teachers should then be an experienced man who can direct and guide the others.* On the other hand, laboratories which accommodate only one class are quieter and there is less distraction. Smaller laboratories are better under most circumstances. Several schools have compromised with laboratories large enough for two or three classes.

The space between tables should be not less than 5 feet, and preferably 6 feet. If stools are provided so the students can sit down, even wider aisles will be required. Since the center aisles must accommodate reagent shelves, balances, blackboards, tables for centrifuges, and other equipment, they should be made at least 8 feet wide, for they are actually work-areas rather than mere passage-ways.

Reagent shelves should be so placed that no student will have to go far to reach them. They should carry all the chemicals required (except those which cannot safely be left on open shelves, such as alcohol, sodium and white phosphorus) and should be kept well stocked at all times. The laboratory should be provided with a bulletin board, periodic table, electromotive series, barometer and ample blackboard area (blackboard costs very little more than finished wall and the utility will justify the investment).

Every laboratory should be provided with fire extinguishers, blankets and a first aid cabinet.

Many types of locks are available but the most satisfactory is a master-keyed combination padlock (figure II.11). Care should be taken that the lock is of corrosion-resistant metal. It may be necessary to interchange locks from time to time, or to reset the combinations, but this is easily done. Master-keyed cabinet combination locks are also available, but they are not so easily interchanged nor so easily removed if they fail to operate.

ADJOINING ROOMS

If the laboratory is not equipped to serve as a classroom, a room should be provided close by where the instructor may explain the theory of the experiment which is to be performed or where he can take a group of students for discussion or study.

There is always a tendency for students to write up their experiments after they leave the laboratory, relying on memory for the results of the experiment. This is particularly true if they stand while working in the laboratory. Under these conditions it is wise to provide a table in the laboratory, or in an adjacent room, where students may record their results at once.

The balance room should not open off the laboratory because of the danger of corroding the balances. It should be close, however, so students may reach it easily and so the teacher may supervise those in the balance room as well as those in the laboratory. The balances should be accurate enough to weigh to one milligram—more accurate if experiments are being done on a semi-micro scale. There should be at least one balance for every four students in order to avoid congestion and waiting. Proper use of the balance is learned slowly and the teacher should be able to supervise the balance room closely.

The storeroom may open directly from the laboratory but this is not necessary if the reagent shelves are well stocked. One storekeeper may adequately serve about 100 students working at one time so a single storeroom will do for four small laboratories. If the laboratory is in constant use, the storekeeper will need an assistant to refill bottles on the laboratory shelves and to make up solutions. The unknowns for qualitative analysis may be kept in the same room if adequate provision is made for safeguarding them. In actual practice it has been found easier to have a separate room for unknowns. This room may also be used for records and for special chemicals.

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* Bailar, J. Chem. Education, 24, 327 (1947).

5

THE ANALYTICAL CHEMISTRY LABORATORY

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In this section is given a discussion of laboratories for quantitative inorganic analysis. In the first part the kind of laboratory and special facilities required for the introductory courses are described. In the second part facilities required for research are considered. The requirements for qualitative inorganic analysis, for organic analysis, and for gas and fuel analysis are not included in this section; work in the first of the three subjects named is taught in the same laboratories as are used for general chemistry, while work in the latter two subjects is carried out in laboratories as described in the sections on organic chemistry and chemical engineering, respectively.

LABORATORY FOR THE INTRODUCTORY COURSE IN QUANTITATIVE ANALYSIS

1. The arrangement of the laboratory is similar to that used for general chemistry. It differs from the latter principally in that some additional facilities are required and that a larger floor area is needed for the same number of students. The details of the arrangement are determined mainly by the available space, therefore no rigid specifications can be set up; instead, a description is given of an arrangement which has been proven to be satisfactory for relatively large classes in quantitative analysis. It is believed that laboratories of any desired size can be modeled on the one described herein.

An essential point in the design of any student laboratory is the economical utilization of the available space. This requires careful planning of the individual lockers and of the relation of locker space to work space. With the design of tables and lockers described in the following paragraphs, an old laboratory which contained 280 lockers was remodeled to contain 440 lockers.

The total floor space in the L-shaped room, excluding balance rooms, office, and stock room, is about 4600 square feet. The arrangement adopted to give 440 lockers and to provide table space for 150 students at a given time is shown in figure II.12. In order to make efficient use of the existing space, the laboratory tables were built in three different lengths. The overall lengths of the tables are 14′4″, 15′7″ and 19′2″. All the tables are 43 inches wide. One table gives ample work space for eight or ten students at a time. The spacing between the tables had to be varied as shown in figure II.12 because of the permanent building supporting columns which are located in the room. Dependent upon whether such a column is present or absent, the aisle space between tables varies from 5′9″ to 4′2″. These dimensions have been proved in student use to be satisfactory.

2. The type of locker is dependent upon the amount of equipment loaned to each student. It is determined, therefore, by the number and nature of the assigned experiments. In many universities, two introductory courses are offered in quantitative analysis; one, a one-quarter or one-semester course for students whose major specialization is outside chemistry, the other a two-quarter or two-semester course for students in chemistry and chemical engineering. In most introductory courses, essentially the same kind of gravimet-

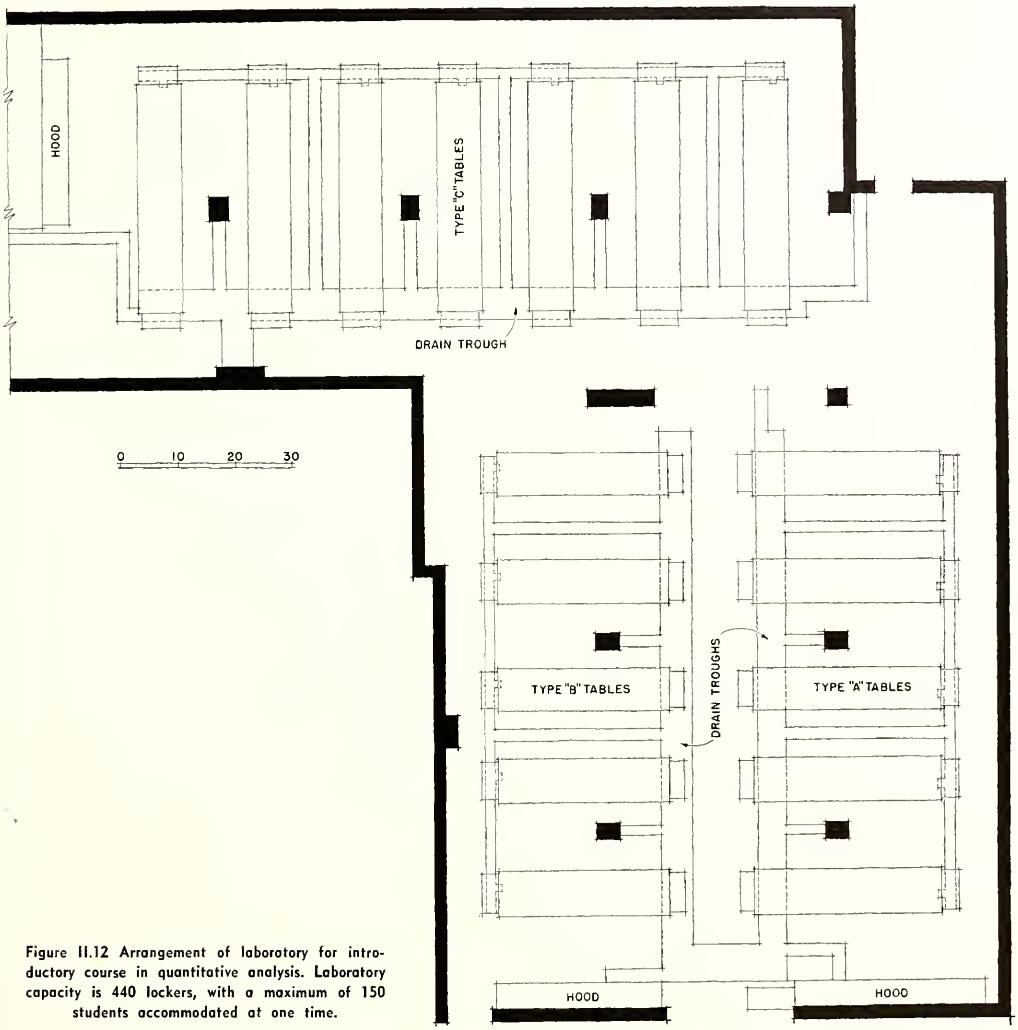

Figure 11.12 Arrangement of laboratory for introductory course in quantitative analysis. Laboratory capacity is 440 lockers, with a maximum of 150 students accommodated at one time.

ric and volumetric determinations are done, with some work in electroanalysis and colorimetry.*

For the customary introductory course in quantitative analysis, it seems unavoidable that a substantial amount of permanent equipment be issued to each student. This is in contrast to the procedure often followed for courses in general chemistry of issuing relatively small amounts of permanent equipment and requiring the student to obtain from the stock room, for one day's use, whatever additional equipment is needed for a particular experiment. However, relatively few experiments in quantitative analysis can be completed by a beginning student in a single period. This is shown by the fact that as many as ninety laboratory hours may be required for nine or ten experiments. Therefore, a fairly large amount of equipment and storage space must be allotted to each student.

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* A description of courses taught in various educational institutions is given in J. Chem. Education, 25, 586-617 (1948).

The following list of equipment is considered satisfactory for the usual courses including gravimetric or volumetric analysis:

8—beakers, 150 to 600 ml.
2—1-liter bottles
2—burettes
2—Gooch crucibles
4—porcelain crucibles and covers
1—desiccator
5—Erlenmeyer flasks, 50 to 250 ml.
2—Florence flasks
2—volumetric flasks, 50 and 250 ml.
1—suction flask
4—funnels, 1 funnel arm
2—burette funnels
2—graduates, 10 and 50 ml.
2—pipettes, 5 and 50 ml.
1—spot plate
2—test tubes
1—thermometer, 360°C
8—watch glasses
2—weighing bottles
2—Witt plates
2—burners
1—clamp
1—iron crucible
2—iron rings
1—tong
2—clay triangles

In addition to the equipment listed above, which is returned by the student at the end of the course, a kit containing a few inexpensive "non-returnable" items is issued. This kit contains matches, towels, wire gauzes, labels, etc. During the course, the student borrows, as needed, special equipment such as platinum crucibles and electrodes.

It will be seen that ring stands are not issued. Ring stands of the conventional kind have been replaced by adjustable vertical rods which remain permanently on the tabletop. Each rod is fastened to a swivel arm which, in turn, is fastened to a shelf above the table. The swivel arm permits the rod to be moved and clamped anywhere within a semicircle of 14 inch radius or to be pushed out of the way against the shelf. Two of these stands are provided at each work space.

It will be noted also that two burettes are recommended to be issued to each student. Burette calibration ordinarily is required in the introductory course for chemists. Burettes are stored conveniently in a special small drawer 32 inches long which extends through the table.*

All the equipment listed above can be stored easily in the locker. The approximate internal dimensions of the locker are: height 33", depth 17", width 12". The recommended locker contains one shallow (4 inch) drawer and one deep (7 inch) drawer, as well as one half-shelf and the above-mentioned burette drawer. The smaller drawer may be partitioned into compartments to accommodate various small articles such as crucibles, triangles, etc.

3. The introductory courses taught in the laboratory under discussion require three 3-hour laboratory periods per week. Since three different laboratory sections are offered, each student during his assigned laboratory periods has a working space equivalent to three lockers. This varies in different tables from 3'7" to 3'10" in length. Each table has a total width of 3 feet 7 inches. A drain trough 7 inches wide down the center of every table reduces the depth of the working space on each side of the table to 18 inches. This amount of space has been proven to be adequate for comfortable and uncrowded work. The tabletops are 3 feet 2 inches from the floor; this height was chosen for the average person standing at his work. It is not recommended that students be provided with stools for laboratory periods two or three hours in length.

4. The materials and details of a satisfactory table for quantitative analysis are discussed elsewhere in this book. "Alberene" stone can be recommended as a satisfactory material for the tabletop (see page 18); other materials could be used, e.g., Carrara glass as in the analytical laboratory of the Massachusetts Institute of Technology.† Two sinks are provided for each table; the previously mentioned trough occupies the center of each table and drains, by reason of a slight inclination, into one of the sinks. The trough is built on the tabletop, with "Alberene" sides and a lining of sheet lead.

5. The balance room or rooms must be separated from the laboratory proper so that balances may be protected from corrosive fumes. Since students may have to carry desiccators or other bulky objects as well as notebooks to and from the balance room, it is essential to plan a location which is convenient to the laboratory and to which easy access can be had without danger of crowding in the corridors, aisles, or doorways.

Shelves or tables about 36 inches from the floor are at the correct height for the average person seated on a stool. Shelves, at least 20 inches deep and from 30 to 32 inches in length, should be allowed for each balance. A balance should not be placed next to a window or a radiator, or placed so that the person using it faces a window. The analytical weights may be best stored in a small locked box adjacent to the balance.

6. Apparatus for analysis by electrodeposition must be provided in amount and kind determined by the enrollment in and nature of the particular course. Almost always it will be satisfactory to assign simple electrolytic determinations on a staggered schedule so that maximum use may be made of the expensive platinum

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* A photograph of such an arrangement is shown by C. D. Hurd, J. Chem. Education, 24, 333 (1947).

† G. G. Marvin, ibid., 329 (1947).

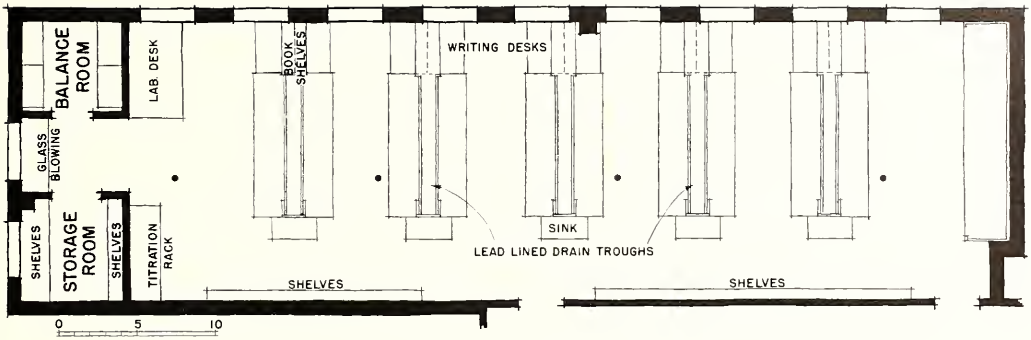

Figure 11.13 Arrangement of Research Laboratory accommodating 10 workers.

electrodes. For a course in which only one simple electrolytic determination is required, e.g. of copper, which may be done easily in a single laboratory period, it is unnecessary to provide more than ten or fifteen electrodes and electrode positions for classes containing 150 students. Such apparatus may be located on a shelf 20 inches deep and 10 to 15 feet in length, along any convenient wall.

Suitable hoods must be provided either as individual small hoods at the work tables or as a few relatively large hoods of the ordinary sort. The latter arrangement is preferable from the standpoint of economy although the former is more convenient for the student. If large hoods are used, not less than the equivalent of 60 feet in length of hood space should be provided for a laboratory accommodating 150 students at one time. The hoods should be equipped with gas, water, air, and either gas or electric hot plates.

It is desirable to provide a room in which solutions may be concentrated or evaporated slowly. This may be done conveniently in a steam room in which a bed of gravel or sand is heated by steam pipes. A room of some 80 square feet would be entirely adequate for this purpose.

The number, construction, or location of reagent racks, drying ovens, calibration balances, coarse balances, and similar facilities will depend on the nature of the individual course and need not be given detailed consideration here.

In institutions of small enrollment, one central stockroom may suffice. When one hundred or more students are enrolled in a single course, it is essential to provide separate stockrooms, one serving the analytical laboratory, another the organic laboratory, and so on. In this way the main stockroom can be reserved primarily for advanced students and research workers.

Finally, consideration should be given to the laboratory office. This must be of sufficient size to permit meetings of all those staff members and assistants engaged with the particular courses. Aside from this purpose, it serves as a storeroom for the "unknown" samples which are analyzed by the students and as the place in which the records of the students are kept.* Unless the samples for student use are purchased already analyzed and packed in individual vials, provision must be made for the preparation, analysis, and bottling of the samples by some member of the laboratory staff. For the laboratory described above, it has been found that an office with a floor space of about 220 square feet is adequate.

LABORATORIES FOR ADVANCED WORK AND RESEARCH

Laboratories for many advanced courses in analytical chemistry may be patterned on a smaller scale on those used for the introductory course. Dependent on the nature of the course, additional special facilities such as a muffle furnace or vacuum ovens may have to be provided. Laboratories for courses of a highly specialized nature, e.g., instrumental methods of analysis, have to be planned on an individual basis, much as described in the section on laboratories for advanced work in physical chemistry.

In considering the design of laboratories for research in analytical, as well as in other branches of chemistry, the choice must be made between laboratories accommodating one or two workers and laboratories accommodating larger numbers. Aside from the obvious economies of space and equipment to be gained by the use of the larger laboratories, there is much to be said for the latter from the educational point of view. It is especially desirable for new graduate students just beginning research to have the opportunity of observing the methods and procedures of the experienced workers. Based on these considerations, the research laboratory described below was planned to accommodate ten workers.

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* A detailed description of the record system and methods used in a large University is given by W. M. MacNevin, J. Chem. Education, 25, 589 (1948).

The room has the approximate dimensions 63' by 18'. It contains five laboratory tables arranged as shown in figure II.13. Each worker has one-half of a table for a work space plus a writing desk immediately adjacent to the table. The tables are 9 feet in length and 5 feet in width. The width is somewhat greater than is customary in similar laboratories; it was decided to sacrifice, if necessary, some of the aisle space between tables to allow tables of this width, which is sufficient to permit the installation of relatively complex apparatus and the use of such bulky equipment as precision conductance bridges. As in the laboratory for the introductory courses, the "Alberene" tabletop is 3 feet 2 inches from the floor. One sink is provided for each table as well as a lead-lined drain trough, 4 inches in width, down the center of each table.

Drawers and cupboards of the usual sort are provided. One cupboard space in the center of the table is left empty to provide knee space so that the worker may sit comfortably on a stool. Each table is provided with 3—110 volt AC and 1—110 volt DC outlets, as well as one outlet which can be used for low voltage from a power supply in a corner of the laboratory. An additional electrical connection is provided between all the tables in the laboratory. This simple arrangement eliminates the necessity either of moving bulky equipment such as recording potentiometers or polargraphs, or of making improvised connections around the room when two or more workers want to use such equipment to measure or record the results of experiments carried out at their own work space. Gas, air, water and vacuum are available on every table: one specially desirable facility is considered to be a gas line at every table which is used for nitrogen and is supplied from tanks in a corner of the laboratory. This avoids the inconvenience of carrying nitrogen tanks to various parts of the laboratory; since the entire system is contained within the laboratory, any leak in the line may be located readily and corrected. Two storage shelves are provided on each table.

The writing desks (two per table) are 2'5" deep, 3'3" wide, with one drawer and three book shelves.

A balance room large enough for four balances is provided by partitioning a corner of the laboratory and is specially ventilated so as to be free from fumes. A small asbestos-topped bench is equipped for simple glass blowing. The titration rack is especially convenient for occasional titrations. It allows the storage of four of the commonly used standard solutions of volumetric analysis, in large bottles protected from atmospheric contamination. The bottles are connected by an automatic syphon arrangement to burettes. The burettes and the titration table are illuminated by daylight fluorescent lamps.

6

THE ORGANIC CHEMISTRY LABORATORY

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Organic laboratory design, in common with laboratory design generally, has undergone a gradual process of evolution during several decades. Those contemplating construction of an organic laboratory will discover that they are the beneficiaries of persons having similar problems in the past who planned carefully and built wisely. Each new building, however, involves particulars which call for careful planning to accommodate the local situation.

Consideration of organic laboratories falls logically into three categories: the elementary laboratory, the research laboratory and special laboratories. Each of these will be considered in turn.

THE ELEMENTARY ORGANIC LABORATORY

The size of the room and the number of such rooms are local problems, but it is far better for the planning chemists to specify the preferred size than for the architect to fix the size arbitrarily. Ordinarily a laboratory may be designed for use each week by three or four sections. The size of the class then governs the size and number of the laboratories.

Flooring is also a local problem. Cost may be the determining factor. Such materials as wood, concrete, ceramic tile, asphalt mastic, and asphalt tile are used. Ceramic tile is used at Mellon Institute, mastic flooring at Princeton and asphalt tile on concrete at Northwestern. Of these three, the first is the most expensive and the last is the least expensive. Although asphalt tile is penetrated by organic solvents, it is interesting to note that this has caused no problem in eight years of use at Northwestern. Solvents, if spilled, may be wiped up or allowed to evaporate. Replacement of damaged squares of tile is a simple matter, but no such replacements have been necessary to date because of damage by solvents. The following experience in the writer's laboratory is informative. Several bottles of organic solvents, including furfural, xylene, pyridine, acetone and chloroacetone, were spilled on the asphalt tile flooring as the result of an accident. Several hours elapsed before it was discovered at which time loose solvent (and some asphalt) was wiped up with towels. Care was taken not to step on a softened surface. After a few days of drying, the floor was as firm as ever.

If daylight is to be used for lighting, generous-size windows should be provided and the room should not be too deep. Even so, students will probably wish to use electric lights most of the time. Since only part of the tables may be used at certain times, it seems wise to plan the wiring circuits with this in mind. The switches should control rows of lights parallel with the tables.

The problem of overcoats is one to consider while planning a laboratory. It is a simple matter to build a coat room as an integral part of a laboratory. This useful provision makes it difficult for overcoat thieves to function. Also, it avoids the necessity and inconvenience of lockers for a large group of students.

It seems wise also to provide for an attached balance room, even though present experiments may involve no work with the analytical balance. Times may change.

An attached stockroom is also a great convenience to the smooth functioning of an elementary organic laboratory. Chemicals and special apparatus for the course may be stored therein, so as to avoid unnecessary wear and tear on the main stockroom.

The laboratory itself should contain tables, hoods, ventilation ducts, services and protective devices. Rows of tables should be placed 10 feet apart between centers. The choice between wooden tables and steel tables is not a fundamental matter but rather one of personal choice (see page 20). Because of the problem of rusting, it is imperative that steel tables be inspected at regular intervals, but wooden tables also impose a maintenance problem. The greater cost of steel tables is another factor to consider. There are differences of opinion regarding the best material for the top of the table. The writer prefers "Alberene" stone but it should be of good quality. "Alberene" containing veins of calcite should be avoided. Careful specifications should be drawn up for selection of stone of the proper quality. Most houses dealing in laboratory furniture also offer competitive material for tabletops which may consist of a thin layer of resistant material on a wood base (see page 18). In the writer's opinion no thin-coated layer provides adequate protection. Prospective users who are considering such materials should obtain samples and submit them to rigorous tests (acid, alkali, solvents, scratching, etc.).

A satisfactory unit table should be of approximately these dimensions: 22 inches wide, 2 feet deep, 3 feet high. Three such tables (for three sections) provide a working surface 6 feet long. At Northwestern such a section is separated from the next section by a sink (14 inches wide). The convenience of the latter is obvious, but the determining reason in our planning was for safety. Thus, because of this separation, student B's burner is less apt to ignite combustible material on student A's table than otherwise. Each sink should be provided with a trap. It is false economy to omit traps even if building laws permit it. Impregnated ceramic sinks or "Alberene" sinks are satisfactory from the standpoint of thermal shock. Hot water may be obtained at the sinks by mixing steam with cold water.

Minimum services on the table should include water, gas, electricity and a squeegee. Steam is nearly as important, and compressed air is desirable. The squeegee is to clean the table. Students seem to enjoy "squeegeeing" their tabletop at the end of a laboratory period, whereas they object to the use of a sponge.

A vacuum line is not recommended. In the hands of an inexperienced group it is apt to be a source of trouble. A water aspirator pump on each table is recommended instead, delivering into a center trough. A piece of cloth, wound around the end of the aspirator pump, makes for a simple and efficient anti-splash and silencing device. Over-size water pipes (2 inches or more) should deliver water to these tables, and 1-inch pipes deliver from the large pipe to the tap. There should be sufficient water pressure for everybody to carry out vacuum distillations concurrently, if desired. Satisfactory water pressure is most important.

If steam is provided, a steam bath is also called for. Choice must be made between a fixed steam bath and a portable one. The mobility of the latter and the fact that it releases valuable table space when not in use are strong arguments in its favor. A suitable steam bath may be made of aluminum.

Each of the services should have a shut-off valve at each row of tables. With a little foresight on the part of the architect, it is possible to have all such valves behind a single panel.

The utility shelf, above the service pipes, should be low, but, to attain this end, the service pipes must be collected as compactly as possible. Usually, not enough attention is paid to this feature of table construction with the result that the shelf may be 24 to 28 inches above the tabletop. A height of 16 to 18 inches is readily achieved, thereby greatly improving the appearance of the laboratory and making the shelf more accessible.

The design of the inside of the table should include drawers at the top for small equipment and shelves beneath them. L-shaped shelves are recommended because they permit more shelf room without otherwise restricting the table. Two L-shaped shelves 6 inches apart are sufficient to store the beakers, Erlenmeyer flasks, etc., and the open part of the "L" makes it possible to store bottles, ring-stands, and other tall equipment. A special long drawer for condensers, glass tubing and the like is a great convenience to the student. Two such drawers should be planned for the pair of tables which are back to back, opposite each other. Each drawer extends into the opposite table, within 6 inches of its door, the dimensions of each drawer being 3" by 5" by 40".

Sliding doors are almost never used in student tables. Opinion prevails that such doors, by sticking, would be more troublesome than the customary hinged doors. Hinges for the doors should be so chosen that the doors may open a complete 180°. Unless the doors open flush with the panels, they protrude into the aisle and are constantly in the way. Below the door the support or framework of the table should be set back a few inches to provide toe space while standing at work.

How many hoods should be provided for an elementary laboratory is a debatable question. Usually, space or finances will not allow more than one hood for every four to eight students. Experiments such as the preparation of acetyl chloride or the Friedel-Crafts reaction are best prepared on the open table in spite of the evolution of hydrogen chloride gas. The elementary organic laboratory should be the place where a student learns how to build an efficient set-up for his experiment. The presence of a hood in the laboratory should not change this principle. At times, however, hoods are valuable. The design of efficient hoods, with adjustable baffle plates and ordinarily without doors, has been well worked out and needs no particular comment (see pages 31 and 61).

An architect who has never designed a laboratory before is likely to underestimate the problem of ventilation. Incoming and outgoing air ducts should be on opposite walls to avoid pockets of unchanged air. This is in contrast to a common practice of placing incoming and outgoing ducts near each other on the same wall.

A portable chest for crushed ice, with sliding top panels, is a great convenience in the organic laboratory and space should be provided for it. Space for a cork bin should be anticipated also.

A protective shower with a drain underneath is a useful safety device to combat fire or corrosive liquids on clothing. The shower should be placed over the doorway. If a chain is provided to start this shower, it should include a convenient handle. Two rings, about 5 inches in diameter, welded together at right angles, comprises the handle devised for use at Brown University. This makes for less fumbling at a time when seconds might be important. Fire blankets may be installed also, but ordinarily both are not used. Portable screens are designed to set on the top of the table. If the screens are made of safety glass, care should be taken to keep flames at a safe distance to avoid blistering. First aid cabinets should be in each laboratory or in the adjoining stockroom. In a convenient design for such a cabinet, the door opens downward, thereby forming a shelf. Finally, blackboards and bulletin boards should be included in the building plans.

ORGANIC RESEARCH LABORATORIES

Just as the above discussion on elementary laboratories pertains to college and university laboratories, so also the following consideration of research laboratories is limited to such institutions. Many of the comments regarding the elementary laboratory apply also to the research rooms. Since research workers need full-time use of the laboratory table, there is no problem of laboratory sections. Drawers and cupboards for the equipment are usually placed below the laboratory table. Two rows of drawers (top row, 17 inches deep, 16 inches wide; second row, 17 inches deep, 33 inches wide) make a convenient arrangement. The cupboards beneath carry adjustable shelving. Services on the laboratory table should include both AC and DC electrical outlets, as well as other services listed earlier. One hood for each two students should be planned. If at all possible, each hood should have its own fan. A heated compartment (with perforated shelving) underneath each hood is helpful for drying apparatus. Writing desks (36 inches wide) at the end of the research table are a great convenience to the student for recording notes, preparing reports and studying.

The writer believes that graduate students learn research methods by observation, hence he prefers graduate students to work in groups rather than alone. Whether the group should be two, four, six, ten, or twenty, however, is another question. Let us assume six for the moment. A compact working unit could be designed for two groups of six sharing a storage room (or apparatus room) between them. This might take a space 70'0" by 23'0" for the twelve persons. The storage room would be 10'0" by 23'0", and each laboratory 30'0" by 23'0". Each laboratory would have a table at either wall with two double tables between them, spaced 10 feet apart at the centers. The 23-foot wall would be fitted as follows: study desk, 3 feet; table, 11-12 feet; sink, 1 foot 6 inches; aisle, 4 feet 6 inches to 5 feet 6 inches; hood, 2 feet. The doorway to the equipment room would be at the aisle, and the hoods would face the windows. Except for two doors, the 30-foot wall could be lined with hoods. The plan could be modified easily to provide rooms accommodating four instead of six persons. The apparatus or storage room would contain such items as a balance, oven, shaker, apparatus awaiting use, etc.

It is apparent that if the authorities stipulate rooms only 20 feet deep, 3 feet must be lopped off somehow. The most obvious way is to eliminate the doorway connecting the laboratory to the apparatus room, and to place the hoods there instead. This would limit the room to two hoods, by reason of which the room should then be restricted to four students. The apparatus room could still be adjacent but it would have to be entered from the hallway. Eight or twelve students could be assigned to one such room.

Safety showers should be placed above the doors of each research laboratory, but it is unnecessary to place floor drains under each one, since such drains add greatly to the expense. The position of the shower should be carefully determined by the architect, so that no apparatus or equipment is beneath it.

Single research laboratories are desirable for postdoctoral fellows or for other persons possessing demonstrated research skill.

Advanced organic work calls for many special-purpose rooms, most of which are important from a research point of view. Some of these will be listed briefly.

SPECIAL ORGANIC LABORATORIES

Organic preparations.—A laboratory for preparations should be installed if this course is part of the curriculum. Tables and hoods similar to those in the research rooms are advisable, but the room may be larger to accommodate a larger group. Two sections may use the facilities. It is advantageous in such a room to leave open at one side of the room a 10 to 15 foot space so that equipment may be built up from the floor. Services should be accessible at the wall. For such open areas, the room becomes more flexible if provision is made for suspending materials from the ceiling. Steel T-shaped slots, imbedded in the concrete ceiling, serve well for such a purpose. If desired, a mezzanine platform may be suspended from such slots.

Qualitative organic analysis.—If qualitative organic analysis is taught regularly, it is well to provide for it in the building plans. Comparatively small table space is required, and nothing unusual about table design is necessary. Ample shelf space for reagents is necessary, however. A coat room is desirable if the size of the group warrants it. Two other features should be incorporated: one, a balance room, and the other a small storeroom capable of storing the samples which are issued as unknowns for the course.

Analytical laboratories.—Consideration should be given in the planning for the location of combustion furnaces for organic analyses. Possibly also a microanalytical laboratory will be in the building plans, in which case it is well to consult a capable microanalyst for such details as he would suggest for the smooth operation of such a room.

Cold room.—A cold room which is equipped with a laboratory table and hood is a useful adjunct of a research laboratory. Temperatures should be maintained at about 3° to 5° C. A room at still colder temperatures may be attached to this room for purposes of cold storage. If the cold room is provided with a hood, it must be so designed that air is taken from outside and not from the cold room itself when the hood is operating. This calls for a closed hood rather than an open one. The air intake is underneath the hood.

Special equipment.—To avoid the embarrassment of having no place to store centrifuges, autoclaves, special distillation equipment, standard taper glassware, and the like, it is wise to anticipate placement of such items in the building plans.

Tall shaft.—Sometimes experiments calling for very tall shafts are conducted. One hears of 50-foot distillation columns. Whether or not such devices would ever be used in a research building, it is a simple matter to plan for them by having a tall shaft with detachable flooring, running from the bottom to the top of the building, with services on the wall of the shaft at each floor level. This could accommodate experiments in distillation or extraction or any other type of work calling for excessive height.

Instrument rooms.—There is merit in collecting expensive instruments in one place and having some professor in charge of the room. In this way the instruments are always ready to be used, but provision for such a room would usually need to be planned with the building. Such instruments would be of interest to both organic and physical chemists; hence the planning for the room should be done jointly by these groups.

7

THE PHYSICAL AND ELECTROCHEMICAL LABORATORY*

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The facilities for laboratory instruction in physical chemistry—comprising those for elementary courses, for advanced courses, and for graduate resarch—are in general more diversified than those for other divisions. Even at the elementary level the great variety of physical-chemical apparatus and experiments imposes special conditions which affect the distribution and utilization of space and which are differently met in different institutions. Thus, there may be a wide difference in the number of experiments to be performed during the course. Regarded as a service course for other divisions of the university, physical chemistry is subject to greater variations in laboratory requirements than are the other branches of chemistry. Moreover the materials for instruction in physical chemistry are more costly than those for other courses, so that budgetary considerations exert more than average influence on the layout of the course.

In addition to these items of variation, an important element in the administration of the elementary laboratory is whether the basis for the assignment of laboratory space is the individual student or the separate experiment. According to the first of these methods, each student is assigned a laboratory kit and tabletop which he uses throughout the course, supplementing the equipment provided by withdrawing from the stockroom such special apparatus as may be required for each new experiment. According to the second method, suitable space is allotted in the laboratory for each experiment, with all the necessary apparatus assembled on the tabletop or stored underneath in drawers and cupboards; the students proceed in rotation from one experiment to another during the course. Between these two extremes many intermediate systems of administration are employed.

Consideration of the educational advantages and disadvantages of these two systems would be inappropriate to the present discussion which is concerned only with the physical aspects of the problem. In this connection, however, it is permissible to point out that the second method will permit the accommodation of the larger number of students per semester within a given laboratory space. Two sufficient reasons may be cited for this. First, some experiments in physical chemistry (e. g., those requiring the use of a thermostat or of certain optical equipment) require space not suitable for assignment as permanent working space for an individual student; if the practice of personal table assignment is followed, a student while performing one of these particular experiments leaves his own tabletop unused. Second, the number of sections accommodated in the laboratory can be made larger by the student-rotation method, the upper limit being fixed only by the number of hours of the day or night during which supervision can be provided.

For the reasons cited the design of laboratories for physical chemistry appears to be to a greater extent an individual matter than is the case with the other major divisions. Whatever may be the merits of the system employed, it is not to be expected that in extending their facilities the members of a department will be apt to introduce any revolutionary changes in method. Rather the tendency will be to continue those practices which have been tested by their own experience and found satisfactory under local conditions. At the same time, the designing of a new laboratory affords its users an opportunity to appraise and improve their methods and to make use of those ideas of others that may prove adaptable to their own purposes. In the attainment of these objectives an examination of some typical solutions of the general problem are of value. One such solution—put literally in concrete form at the University of Michigan—is here presented with recognition of the fact that since the constants and variables of the problem will differ in different institutions, the methods of attack and the answers reached will not be the same. In the solution of our own problem we were aided by a study of such information as we could gather from reading and from talking to others. I should like to point out, however, that by far the best method of collecting the necessary data is to make a tour of inspection of other laboratories.

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* Presented before the Division of Chemical Education at the 111th meeting of the American Chemical Society in Atlantic City, April 14-18, 1947.

The University of Michigan has just completed construction of an addition to the chemistry building which nearly doubles the present useful floor area of approximately 70,000 square feet. (This figure is exclusive of space for corridors, stair wells, elevators, toilets, machinery service rooms, tunnels, etc.) All-metal furniture is used throughout the addition. To the maximum extent possible all service lines are exposed on the walls and ceilings for easy access. Attaching the addition to the existing structure has to a considerable extent dictated its arrangement, although no attempt has been made to match the present building either in architectural or mechanical features. Thus, for example, in order to obtain the floor space the addition has been constructed with four floors and full basement. Since the old building lacks a basement, the first floor itself being somewhat below grade, the floor levels differ between the old and new buildings and require a system of interconnecting corridor ramps. This is a price gladly paid for the increase in space. On the other hand, however desirable might have appeared certain changes in the distribution of departments among the various floors, considerations of economy made it necessary to continue the present general arrangement. Thus, each major division has extended into the addition at its present level, with general chemistry on the fourth floor, analytical for the most part on the third, organic on the second, and physical chemistry on the first.

There were two student laboratories for physical chemistry, occupying with their adjunct rooms about 3200 square feet. Including some reallocated space in the old building, added facilities include a laboratory for elementary work and one for advanced work, each with the necessary auxiliaries of an optical room, a balance room, an apparatus room, and an assistant's room.

The new elementary laboratory, located in the old building, is about 40'0" by 45'0", the attached rooms mentioned bringing the total floor area to about 2500 square feet. In the new laboratory the present system of administration is continued, according to which each student is assigned a locker consisting of a drawer and cupboard to store his equipment. The latter consists of the usual assortment of basic laboratory apparatus, supplemented as required by the special apparatus needed for certain experiments. The student performs most of the experiments on his own 5 foot tabletop. (Services provided are cold water, gas, air and AC electricity.) About three-fourths of the floor space in the new laboratory is occupied by such student tables, providing accommodations for thirty students in each of four sections. The remainder of the laboratory is equipped with special tables for such experiments as surface tension, freezing point, and heat of reaction. One of these has a built-in thermostat which carries a line of overhead shafting operated by a relatively quiet dental motor. This is to provide power for a number of experiments requiring stirring or shaking operations.

A table with a "Transite" top along one wall mounts a drying oven and is equipped for glass working. The usual wall shelf units, partly with doors, partly without, are used for storage of dry chemicals and solutions. We find 1½ to 2 lineal feet of shelving per student adequate for such storage purposes in the laboratory. Distilled water is supplied at one sink only.

As already indicated, auxiliary rooms are provided for optical experiments, balance rooms, apparatus storage, and an assistant. With regard to equipment storage we find it most satisfactory to refer the student to the general stockroom for ordinary laboratory supplies but to retain under control of the staff most of the special pieces peculiar to physical chemistry.

In the completed building there are two laboratories for advanced physical chemistry. One of these, a very well-equipped laboratory for electrochemistry, has been in use for many years in the old building. A new one, for all other types of advanced work, is on the first floor of the addition. Before entering into details concerning the layout of this laboratory, I should perhaps explain that among what we call "advanced experiments" we include individual projects designed to afford some measure of the student's adaptability to research. With this in mind, the new advanced laboratory, approximately 30'0" by 50'0", is intended to provide easily adapted space for work of many different types. Twenty ordinary tabletops (2'6" by 5'0"), each with three lockers underneath, are provided along the walls and in one center table; the lockers will supply storage space for individual student equipment but it is not contemplated that the tabletops themselves are not permanently assigned to individual students. The sinks in these units are so spaced that uninterrupted table lengths of 5 and 10 feet alternate so that long assemblies may be used if desired. Services provided are gas, air, cold water, 120-volt AC, and battery current from a central distribution system.

The remainder of the central floor space in this laboratory is occupied by three rather liberally spaced 15-foot table assemblies providing for a considerable degree of flexibility in the purposes served. One of these is a vacuum table with the usual lattice work for mounting of glass apparatus. All services are supplied to this unit in turrets at convenient heights at either end of the assembly. Space is available underneath the base for the installation of pre-stage vacuum pumps, batteries, etc.

The other two 15-foot table assemblies in this laboratory each consist of a central island carrying the laboratory services and normally of two tables at each end. The tables, while substantially built, are small enough to be readily portable (four of them are on casters) so that they may be grouped in any desired position about the islands. Both islands are of normal (3 foot) table height, one being 4 feet square, the other 4'6" by 7'6", the latter incorporates a thermostat.

The remainder of the equipment in this laboratory is ranged along the walls and consists of an 8-foot fume hood, an 11-foot table with "Transite" top carrying a drying oven and providing space for glass. A table carrying three analytical balances, a sink for distilled water and also with a hot and cold water mixer, a blackboard, and a small bulletin board. With this arrangement it is hoped that a high degree of adaptability for the performance of many types of advanced experiments has been secured. The range is extended by an optical room (200 square feet) located across the corridor from the laboratory just described. Here again the idea is rather to provide space for individual projects than to assemble equipment for set experiments.

Auxiliaries to these laboratories are an apparatus room (350 square feet) and an assistant's room (170 square feet). In addition, as with all our laboratories in the new building, we have adopted the Northwestern plan of a separate coat room accessible only from the laboratory.

The third type of laboratory space for physical chemistry to which I should like to give some attention is that for graduate or staff research. In our building, the usual two-man research rooms, which will be found scattered through both the old and the new portions, present no unusual features and need not be discussed further than to mention that rather by accident than design their dimensions vary between about 240 and 390 square feet and that we consider it fortunate that some of the larger sizes are available. We do not in general distinguish among the different departments in the assignment of such rooms.

A practice in which we appear to differ from other departments and which is being extended in the new building is the use of much larger research rooms, accommodating from three to six, and in one case up to twelve or fifteen students. The advantages claimed for these larger rooms are : 1. ease of supervision; 2. training in technique for the younger men by observation of those more experienced in similar work; 3. economy of operation; and 4. adaptability of space allotment to the needs of a particular research at different stages in its development. Whether or not we have gone too far in this direction in the case of the largest room mentioned must be determined by later experience. It is only fair to point out that this particular room entered the plan due rather to last-minute nervousness incident from the rapidly mounting graduate enrollment than from a firm conviction that it would prove ideal in size for graduate research in general. For organic research, however, another room of the same size has been a highly regarded part of the plans from the beginning.

The equipment of these larger research rooms needs no special description beyond the fact that in several instances one wall is left free except for services, so that vacuum tables, thermostats, or portable tables can be installed at these locations as needed.

In passing I should like to refer to a valuable suggestion by F. H. Spedding of Iowa State College, as a result of which we have provided removable slabs 3 feet square in a vertical tier of research rooms. The clear space thus available makes possible the use of separation columns of various types up to 40 feet in height. If other facilities of this nature should be required, as seems not unlikely, advantage can be taken of the unused service court in the old building.

In addition to the rooms set aside for graduate-student occupancy, a number of special rooms are provided for the housing of research equipment in physical chemistry. These include a cold room, two constant-temperature rooms, two rooms for electron-diffraction equipment, a mass-spectrograph room, a room for moderately heavy colloid chemical equipment, two dust-free rooms, and a vibration-free room. It will of course be realized that the word "free" used in these connections is for the sake of brevity only, the intent being rather that in these rooms special precautions are adopted to minimize the effects of dust and vibration, respectively. In fact, even in this relative sense the designation "vibration-free" can be applied only to a 3'0" by 11'0" concrete table independent of the room and of the building foundations. Layers of vibration-absorbing materials are interposed in the concrete slab to build the height up to three feet above floor level. A service panel mounted on the floor of the room alongside the table provides gas, water, air, electric, and waste connections, while auxiliary apparatus are either mounted on adjacent tables or supported overhead from 6 inch eye-bolts.

In connection with the two dust-free rooms and the two constant-temperature rooms, it is perhaps worthy of note that complete electrical shielding is provided. For this purpose the walls and ceiling are covered with a copper-clad tar paper. The floor slab contains a continuous copper mesh screen brought up at the edges of the room and soldered to the wall covering. Lights are encased in copper mesh baskets. The electric light and power circuits are supplied through 1:1 transformers located just below each room in the service tunnel. This design for such rooms is employed at the Naval Research Laboratory and was described to us by W. A. Zisman.

Although not directly under the control of the division of physical chemistry, the shop units are of such primary concern to that department that they are appropriately mentioned here.

The shops are located in the basement and consist of two portions, one to be used only by employed mechanics, the other by members of the staff and graduate students but under the supervision of the shop superintendent. The first of these units consists of a main shop (about 1000 square feet), a stockroom, a shop office, and a room for sand blasting, plating, and finishing. For general use a machine shop and a wood shop (about 325 square feet each) are provided. Members of the staff and authorized graduate students only have access to the latter rooms at any time, while the shop superintendent is available during regular hours.

One of the basement rooms near the shops is used for the storage of instruments requiring repair and adjustment. The shop foreman has access to this room and is expected to arrange for repairs as need requires and opportunity offers.

In completing this brief description, I should like to emphasize that it is not my intention to present our laboratories as a model but to supply a partial check list of items to be considered by those who may soon be engaged in planning such buildings. As stated earlier, no description, however complete, can be an adequate substitute for personal observation.

8

BIOCHEMICAL AND RELATED LABORATORIES

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A chapter entitled "Laboratories for Biochemical Teaching", by Carl P. Sherwin in the 1930 National Research Committee Report,* directs attention in the opening paragraph to the wide scope of biochemistry because of its close relationship to bacteriology, botany, pathology, physiology, zoology and allied fields. Since that date biochemistry has had a tremendous expansion, particularly in the fields of microbiology, clinical medicine and pharmacology. Colleges of agriculture and schools of home economics have also become very active in some phases of biochemistry.

The greatest part of this chapter will be devoted to a consideration of laboratories for the teaching of biochemistry at both the undergraduate and graduate level since a well-planned and well-equipped laboratory is essential to provide adequate training for the student in what has become a complex and diversified field. It is well known that the biochemist must have many of the skills of the organic chemist, the analytical chemist, the colloidal chemist and the physical chemist as well as extra skills of his own. Since each year more and more pieces of delicate equipment are added to the armamentarium of the biochemical laboratory one could wish for more training in modern physics, especially in that dealing with the field of electronics.

A series of six articles, published in the April, 1947 issue of *Industrial & Engineering Chemistry,* on the general subject "Construction and Design of Research Laboratories" provides valuable information for those who are interested in planning a modern laboratory. An article by C. S. Adams† dealing particularly with the university or college laboratory should be of special interest to those who are engaged in the training of chemists. Although the article is not primarily concerned with a laboratory for biochemistry, many of the points dealing with special rooms are especially applicable to such a laboratory.

A second series of articles published in the *Journal of Chemical Education* in 1947 is prefaced by an article by H. F. Lewis‡ on the general problems of laboratory design. The article should be read by all faculty committee members to whom the responsibility of a new building program is assigned. The general article by Lewis is followed by more specific articles dealing with the general, analytical and physical chemistry laboratories. A separate discussion of a laboratory for biochemistry is not included in this series. This may be explained by the fact that many chemists still consider the biochemist as a physiological chemist who is only concerned with medical students. While it is true that many departments of biochemistry are in medical schools, each year an increasing number of students are requesting courses in biochemistry which are taught from a non-medical point of view. As building programs are completed to relieve the present crowded laboratory space available for teaching and research, there will probably be an increase in the number of students seeking these courses. It is expected that although the teaching of this group will require in most cases the same type of equipment as that used in the medical classes, both the lecture and laboratory work will be planned to give a more general viewpoint of biochemistry.

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* Published by Chemical Foundation, Inc.

† Adams, C. S., Ind. Eng. Chem., 39, 457 (1947). University or College Laboratory. See also page 80.

‡ Lewis, H. F., J. Chem. Education, 24, 320 (1947). General Problems of Laboratory Design. See also page 75.

THE BIOCHEMISTRY LABORATORY FOR UNDERGRADUATE TEACHING

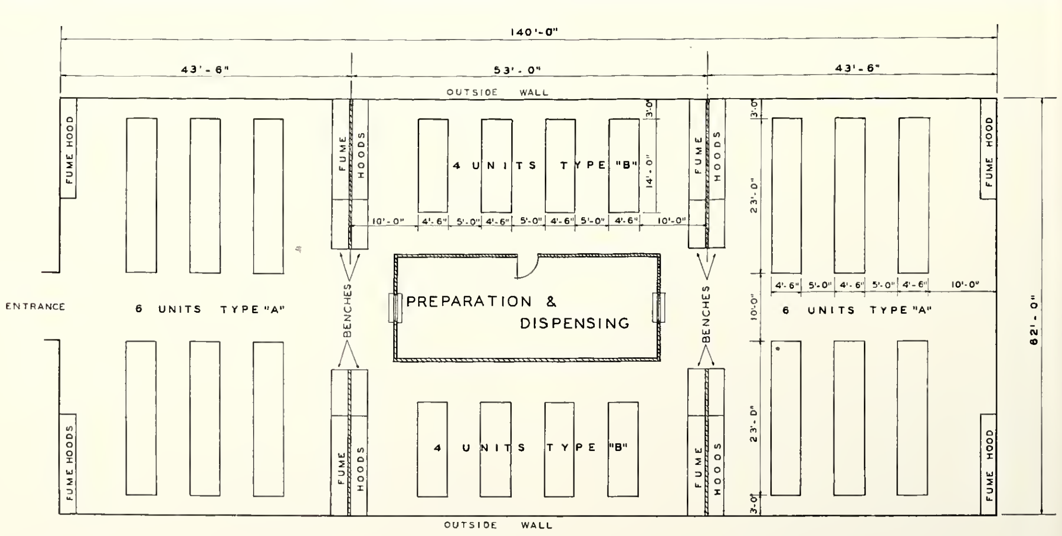
Much of the material presented in this chapter was assembled from data supplied by biochemists from various laboratories in response to a questionnaire. In some cases information was obtained by personal visits to laboratories and by direct correspondence. Fifty questionnaires were sent out and thirty replies were received.

The survey shows that most medical schools are teaching from 50 to 100 students in biochemistry, although several report between 150 and 200 students. One non-medical school reports that 250 students are taught beginning biochemistry. At Michigan medical students, medical technicians and graduate students in biochemistry, chemistry, physiology, pharmacology and bacteriology (170 to 180 students) are given the same laboratory course. Dental students (90 to 100) are taught an alternate and somewhat shorter course. A course for undergraduates and graduates in which the non-medical point of view is emphasized, was started during the past year, and it is expected that this course will have between 25 and 50 students during the next few years. An additional group of 150 students (nurses, dental hygenists and students with majors in physical education) receive a survey course in chemistry which includes general, organic and biological chemistry. Thus, during the school year from 450 to 480 students receive instruction in elementary biochemistry. Since there is at present a trend toward the provision of more adequate medical and dental services for a greater number of people, it can be expected that the actual number of medical and dental students will increase within the next decade. Schools which do not have medical or dental students must deal with increasingly large numbers of graduates and undergraduates in biochemistry and in some cases must supply service courses to departments of home economics and various departments in agricultural colleges.

It thus appears that biochemistry in the near future will be taught, at least at the undergraduate level, to a steadily increasing number of students. The problem of how such large groups of students can be handled efficiently and with the maximum use of floor space must be considered in any building plan.

The questionnaire requested an opinion as to whether 100 to 150 students could be more efficiently handled in one large laboratory or in several smaller laboratories. To the writer's surprise, approximately one-half of the group expressed a preference for a large laboratory. Many of this group have this arrangement at the present time and consider it satisfactory. Several who favored the larger laboratory suggested that, by use of movable partitions, sections of the laboratory may be partially separated and that in this way some of the advantages of the small and the large laboratory may be obtained. A laboratory which would fulfill these requirements is pictured in figure II.14. It will be noted that this laboratory, which by choice would be at the end of the building wing, is 140′ 0″ by 62′ 0″ and

Figure II.14 A proposed biochemistry laboratory. This laboratory contains table space for 336 students and accommodates 168 students at one time.



provides 336 student tables. The end units, which are partially separated from the central unit, contain 120 tables while the central unit contains 96 tables. By adding another row of tables to the central unit, a total of 360 tables could be obtained in 3 units of 120 each. It will be seen that the separation into the three units is accomplished by permanent walls extending inwards 22 feet from the sidewalls at suitable points. It is realized that a laboratory of this size would not be built without an escape corridor at the end of the wing to provide an exit if the entrance to the wing was blocked for any reason.

The main feature of the laboratory shown in figure II.14, however, is the central dispensing and preparation room. Anyone who has had experience in teaching laboratory courses in biological chemistry knows that many special reagents and materials are required which may be moved in and out of the laboratory several times during the semester. It has also been our experience that, since certain reagents and materials are quite expensive, a dispensing window relatively close to the students is an economic necessity.

The central room has been made large enough (16′ 0″ by 40′ 0″) to serve not only as a storeroom and dispensing room for student supplies, but also as a preparation room for many of the student reagents. Equipment and materials in this room are primarily for course work, and a second stock room for advanced students and research workers should be provided elsewhere. Elevator service between this room and the departmental stock room in the basement is desirable. A room primarily for the preparation of quantitative solutions by student assistants must be considered an additional necessity for any laboratory course. Dispensing windows have been placed at the ends of the central room rather than on the long sides to prevent congestion and confusion near the student tables. It might be desirable to have recessed shelves along the walls for certain reagents which are not used too frequently. These shelves may be advantageously fitted with sliding doors operated within the central room so that bottles on the shelves may be readily changed or refilled by the storeroom keeper without leaving the central room.

In response to the question, "How much laboratory table space should be assigned to each student to allow for efficient work," there was again a wide variety of opinion, with some estimates as low as 4 square feet and others as high as 20 square feet. Most of the group, however, considered that 8 to 10 square feet was an adequate working space. By the assignment of alternate tables in the laboratory pictured in figure II.14, each student will have approximately 8 square feet of working space without consideration of the space occupied by the sink or the central part of the table used for services and reagent shelf. If 168 students are assigned tables, each student has about 47 square feet of total floor space after deduction for the central dispensing unit. Several interpreted the question in that manner, and gave values ranging from 35 to 55 square feet of floor space per student as a necessary requirement.

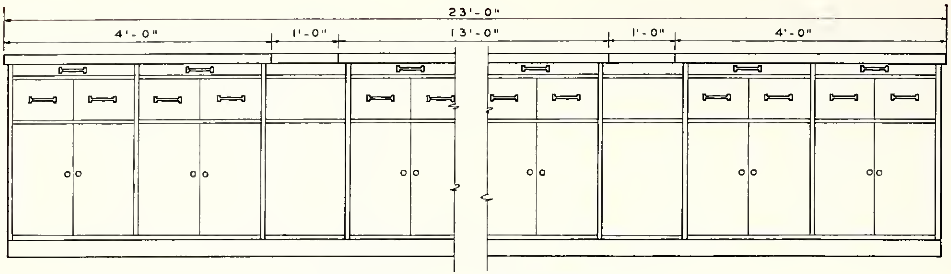
All agreed that the minimum essential services at a student table should be gas, electricity and water. Approximately half of the questionnaires indicated that compressed air and a vacuum line were desirable. Several definitely specified that a water aspirator should be supplied, rather than a general building vacuum line. Only four expressed a wish for a steam line at the students' tables.

A wide variety of opinion exists concerning the best design of a single table unit. Most reports agreed that at least two or three drawers and one cupboard are required. A drawer of 1½ to 2 inches in height for burettes, pipettes, water condensers, thermometers, glass tubing, etc. is a great advantage. Two additional drawers, 6 to 7 inches in height, should be provided for such items as glassware, small beakers, Erlenmeyer flasks, volumetric flasks, small funnels, etc. A cupboard 22 to 24 inches in height and 22 inches in width seems to be adequate for the hardware and larger glass equipment (see figure II.15). The writer would like to suggest that each cupboard be provided with a galvanized wire basket suspended from a side wall which may be used to dry glassware between laboratory periods.

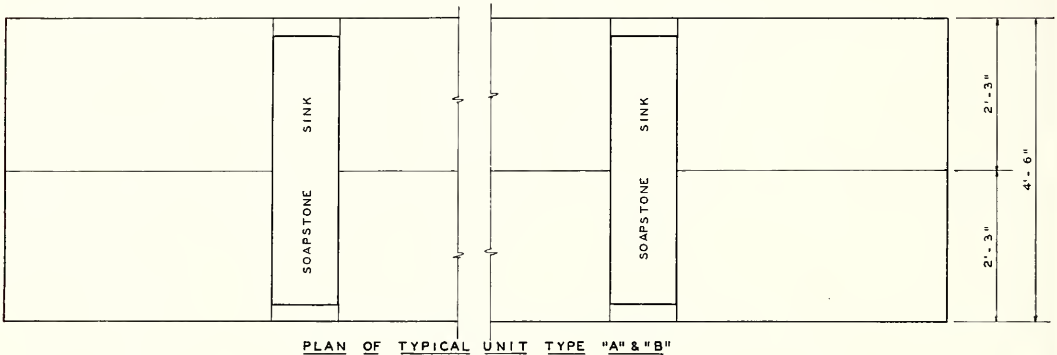
Most of the reports indicated that the arrangement of a central trough and large sinks at the end of the table, as opposed to a medium-sized sink between the working space of two students, was preferred by the greater number of laboratories. The writer feels that although there may be a slight saving in space by the use of the former plan, there are definite advantages to the latter plan. One of the most frequent complaints of those who have used the single sink arrangement is that washing of glassware is neglected or that students tend to clutter up the table space of the students near the sink while engaged in cleaning apparatus. One correspondent, who has just moved into a new biochemical laboratory, states that the student laboratory should have as many sinks per student as the architect will allow. Figure II.15 gives the general arrangement of tables with a sink between the working space of each two students.

Over 70% of those who responded to the questionnaire favored tabletops made of hard material such as "Alberene" or "Kemrock." In the case of one commercial research laboratory, which the writer has visited, lead tops are installed on all the tables in the chemistry division. It was surprising to find that a great majority favored wood cabinets rather than metal cabinets, although several who expressed such a preference stated that they had had no experience with metal cabinets. Although the reports from only six laboratories stated that they would choose metal cabinets, the writer would certainly like to consult this group more fully before making a final decision.

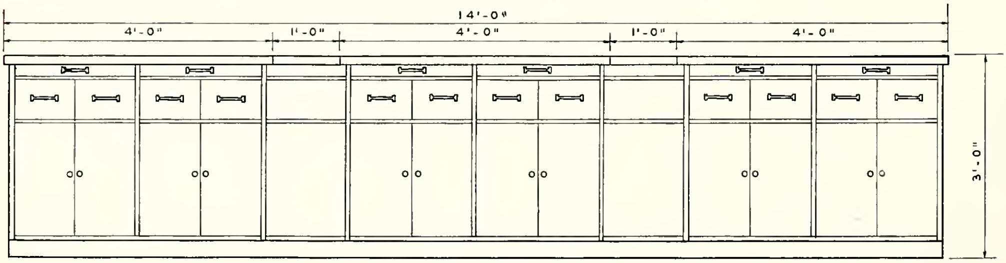
In response to the question concerning the amount



ELEVATION OF TYPICAL UNIT TYPE "A"



PLAN OF TYPICAL UNIT TYPE "A" & "B"



ELEVATION OF TYPICAL UNIT TYPE "B"

Figure II.15

of hood space required in a laboratory designed for 50 students, the average estimate varied from 30 to 50 square feet. A small group believe that a small suction duct or fume trap should be located at every table and the large hoods eliminated entirely. In the plan shown in figure II.14, 4 hoods, 15 feet in length (2 to 2½ feet in depth) have been provided for 60 students. This is more hood space per student than advocated by most of the replies on the questionnaires, but not as much space as was considered essential by other groups. The larger space for hoods in the laboratory shown in figure II.14 should permit one hood or a part of each hood to be fitted with steam baths for removal of flammable solvents. The arrangement of the hoods given in figure II.14 may not be the most desirable. A longer working table along the cross walls could be obtained if the hoods were made somewhat shorter along the width of the laboratory, but extended at a 90° angle for 5 or 6 feet along the long side of the laboratory. A corner hood space, however, is not well utilized.

It was generally agreed that the services supplied to the hoods should be more extensive than those at the individual table and the minimal requirements should include gas, water, electricity and steam. Compressed-air lines and vacuum lines are desirable. Good drainage is also necessary. One laboratory in a research institute has utilized the space under the hoods, which is ordinarily wasted, by the installation of a drying compartment for glassware. Steam for the hoods brought in through a coil of pipes supplies the heat.

Although the main student laboratory must be carefully planned to allow the students to work with maximum efficiency, the teaching program will be handicapped unless small rooms in close proximity to the student laboratories are available for special purposes. Balance rooms, Kjeldahl digestion and distillation rooms, animal rooms for student use, photometric equipment rooms, cold rooms, constant-temperature rooms which can be regulated to above or below the temperature of the main laboratory are among those to be considered.

Nine of 30 laboratories still use the older type of the macro-Kjeldahl method for student use and three of these laboratories have a special room for the digestion procedure. In the remaining six laboratories these digestions are done in hoods in the student laboratory. Distillation is made either on special racks in the student laboratory or on the students' table. The majority of the reports indicate that modified macro methods are used by which the digestion and distillation can be done at the students' table.

In only half of the laboratories from which responses were obtained is the analytical balance used by students in the elementary course in biochemistry. Moreover, some of this group reported that the balances were used to a very limited degree. In our department, 22 balances are available for students in the medical biochemistry course. Each student uses a balance for three to five hours early in the semester for the calibration of volumetric apparatus and then the balances are not needed until the following semester. In planning a new building, one would question whether space for a student balance room should be seriously considered unless the balances are used more frequently. The alternative is to plan a room that can serve not only as a balance room, but also as a room for special experiments or a small demonstration room.

A special room for photometric equipment (photoelectric colorimeters, spectrophotometers, fluorometers, polarimeters) available to both undergraduate and graduate students appears to be used in many laboratories. Although it would be desirable to have such a room for the storage and use of the various instruments and the accessory equipment filters, tubes, cuvettes, lamps, etc.) apart from the main laboratories, it seems inadvisable to open the facilities of such a room for the use of beginning students except for demonstrations or carefully supervised work. A centrally located room of this type for graduate and research students is the ideal arrangement.

With the increasing emphasis on the chemistry of enzymes and coenzymes, several schools have planned student experiments which demonstrate the isolation of enzymes and coenzyme factors. Since in many cases such experiments involve filtration, dialysis or centrifugation at relatively low temperatures, cold rooms for student use must be provided. Nine of 30 laboratory groups who reported on the questionnaire state that students in beginning biochemistry used the low-temperature rooms. While experiments of this nature are usually done by graduate students, it may be necessary to incorporate a reasonable amount of such work into elementary courses if our laboratory techniques are to keep pace with the lecture material.

It has been our experience (confirmed by other laboratories, as indicated by the questionnaire) that small demonstration rooms or special experiment rooms are extremely useful. Such a room providing seating space for 30 to 40 should have a demonstration table or bench equipped with all the common services. The arrangements in the room should be sufficiently flexible, so that it could be readily converted from a small classroom into a small laboratory. The benches, for example, should be movable so that they could be pushed aside if one wished to move in a table for chemical reagents or an operating table for small animals. By taking small groups of students into such a room by rotation all the members of a large class are able to participate in experiments, which, because of special equipment or the use of special techniques, could not otherwise be done. To justify such a room, which presumably would not be used as much as a main laboratory, one correspondent suggests the conversion of a classroom for 70 to 80 people into two such rooms by a movable partition which divides the classroom in such a manner as to give each small room half of the lecture or demonstration table. Another correspondent has suggested that student balances could be placed along the wall of such a room.

The replies to the questionnaire indicate that in many schools experiments involving the use of laboratory animals are done in the beginning course in biochemistry. Some of these experiments are concerned with nutrition studies, others with changes in metabolism brought about by increased or decreased hormone activity. In other experiments, animals are sacrificed to obtain fresh tissues for the study of enzymes and enzymes systems or for the isolation of tissue constituents. In any case, it would appear that a small animal room in close proximity to the main student laboratory would be highly desirable, if not a necessity. Since another section of this book (Part III, Chapter 5) is devoted to the construction and equipment of animal rooms, no discussion of that subject in this chapter will be necessary.

EQUIPMENT FOR THE GENERAL LABORATORY COURSE IN BIOCHEMISTRY

Since many of the quantitative methods of biochemistry are based on colorimetric procedures it was of some interest to note that 13 of 30 reports to the questionnaire stated that most of the students' work was still done on the direct-vision colorimeter. Two of this group of 13 do one determination involving the photoelectric colorimeter while four limit the use of the instrument to a class demonstration. Six laboratories report that half of their colorimetric measurements are done photoelectrically, while 11 laboratories state that 80% to 100% of their colorimetric methods are based on the use of the photoelectric colorimeter. Other optical equipment in general use in elementary courses are the polariscope, the spectroscope, the spectrophotometer and the fluorometer.

The Van Slyke volumetric gas apparatus, the Van Slyke and Neill manometric apparatus and the Warburg apparatus for micro respiration studies are the three most commonly used in biochemical laboratories. Two of the above instruments are manipulated by a mercury column and the third requires mercury for the calibration of the manometers. In that part of the questionnaire concerned with special rooms, the question was raised as to whether a special room should be set aside for instruments involving the use of mercury. Apparently very few laboratory groups have considered this of importance since the answer to this point was negative in 26 reports and only one laboratory states definitely that all determinations involving the Van Slyke type of apparatus are done in a special room. The writer has observed that mercury is handled much too carelessly in many laboratories. In the older laboratories with wood floors in which mercury becomes lodged in cracks, from which it can be removed only with difficulty, the problem of chronic mercury poisoning must be considered. It is appreciated that it might be inconvenient for research workers to use these instruments in a special room. It should be possible, however, to design a portion of the laboratory table from which every trace of mercury lost from a Van Slyke manometric or volumetric apparatus could be quantitatively recovered. If students are to use these instruments it is inevitable that mercury will be lost unless a special type of table is provided. Such a table should have raised edges and a central depression into which mercury can be brushed and drained into a bottle below the table. It is suggested that all cleaning and handling of mercury be done on such a table to minimize the loss of mercury into the plumbing. Such a table or tables would not need to be large and could be portable if desired.

Radioactive elements or tracers are being used more widely each year in biological research. Another problem involving the careful handling of material is thus introduced. In some cases loss of material of strong radioactivity might be a health hazard to laboratory workers, but in any case loss of such material in the laboratory might make later work of this type of questionable value. In planning a new laboratory, the question of handling radioactive isotopes should be considered. In one laboratory visited by the writer, the tabletops in the section of the laboratory to be used for radioactive tracer work, were made of stainless steel to minimize the loss of material (see page 214).

Practically all laboratories use procedures in the general course which involve the use of a centrifuge. The reports indicate that most of the centrifuges used for class work are the small table type or, if the larger type is used, they are run at relatively low speeds. The question was raised whether adequate protection to the student was assured by the operation of these centrifuges in a heavy walled special room arranged so that the centrifuge could be started and its speed controlled from a point outside of this room. The question was prompted because of what might have been a serious accident with a medium-speed centrifuge in this laboratory and the fact that several European laboratories have rooms specially designed for the use of the medium and large-size centrifuges. Since all the answers on this point of the questionnaire were negative, it is assumed that most laboratories feel that no danger is involved if ordinary precautions are taken.

LABORATORIES AND LABORATORY EQUIPMENT FOR GRADUATE STUDENTS

The reports indicated that advanced laboratory courses in biochemistry are given in 20 of the 30 schools responding to the questionnaires. One school reports two courses in advanced laboratory work while a second school reports three distinct advanced laboratory courses. Only eight of the 20 schools giving advanced laboratory courses report the use of a special laboratory for such a course. Most of the groups state that the advanced course work is done at the space to which the student is assigned for research. In response to the question concerning the special equipment used in this course, the most common answer was "all the special equipment that is available in the various research laboratories in the department."

In our present quarters, a room of approximately 1200 square feet has been found to be very useful for an advanced laboratory course. Fifteen students may be assigned from 15 to 20 square feet of table space and still leave ample room for certain equipment which may be shared by the group as a whole. Since students who are starting their graduate work usually take an advanced laboratory course, they are assigned table space in this room and may continue their work there during the next year on their master's problem. Usually by the time the course is to be repeated, the student has been advanced to a smaller research room. It is of interest to note that several prominent departments believe that laboratories to accommodate 10 to 12 students, but otherwise similar to that described above, should be provided for *all* graduate students. In several letters attached to the questionnaires which were returned, it was pointed out that students working together in a laboratory of this size acquire a great many laboratory techniques and skills from each other. With this point in mind, some of the graduate students in organic chemistry at the University of Michigan have been assigned space in the new building in rooms built for 15 to 18 students. Such an arrangement has one additional point of advantage. At the beginning a

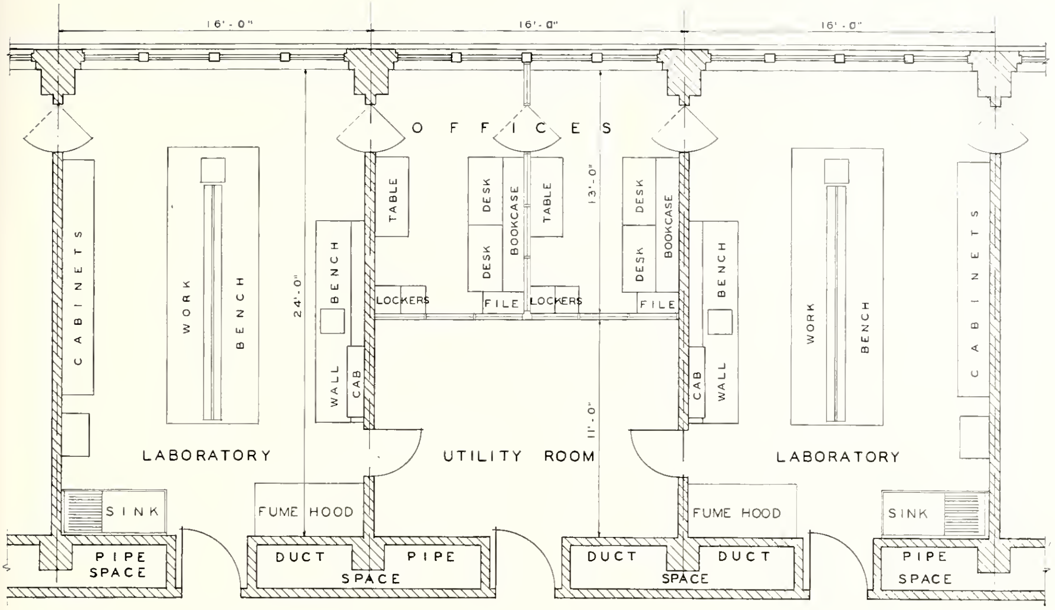


Figure II.16 This standard three-bay arrangement of laboratories was adopted by the Department of Agriculture for their regional research laboratories.

student may need only a small space for research, but as the work proceeds more space in the same room can be readily provided as it is needed.

In response to the question as to whether graduate students should be grouped as indicated above or assigned to rooms designed for two or three students, the majority of votes, however, favored the use of the smaller rooms. The standard three-bay arrangement (figure II.16) is of the general design described in Bulletin AIC-139 of the Bureau of Agricultural and Industrial Chemistry of the Agricultural Research Administration, United States Department of Agriculture. This is a very useful, flexible arrangement adopted by the Department of Agriculture for its regional research laboratories (see page 330). Bays are 16'0" by 24'0" with a laboratory in each outer bay and the central bay divided by steel partitions into a utility room (approximately 11' 0" by 16' 0") on the corridor side and two offices on the window side, each being approximately 13' 0" by 8' 0". The space in the offices, designated in figure II.16 as "table," is intended for balances. The use to which the utility room is put depends on the nature of the work being carried on in the adjoining laboratories. It might be used for photoelectric colorimeters, a refrigerator, a Warburg set-up, constant-temperature baths or any combination of these instruments best suited to the needs of the workers in the adjoining laboratories. It is obvious that each three-bay unit may be altered slightly to meet the needs of a department. In some cases the balances might be moved into the part designated as a utility room in order to provide an additional desk in the office space. On the other hand, the two small offices might be combined into a larger space for a staff member and desks for graduate students placed in the utility room. One point of special interest from the safety point of view is that each laboratory has three exits in case of a fire.

Another arrangement of laboratory and office space for research workers is shown in figure II.17. This is the 3-unit plan of the Merck Research Laboratories for their organic chemistry division (see page 182). One useful feature of this plan is the provision in each laboratory (20' 0" by 20' 0") of built-in space along the walls for desks and filing cabinets for junior workers. The space designated as outer or inner office could be used as in the previous plan for a utility room.

An attempt was made in the questionnaire to obtain some idea of what various laboratories considered to be adequate space for a cold room. Obviously this will vary with the size of the department and the number whose field of research demands such a room. If this room is to be made available to a limited degree for students in the general course, then the figures given below are probably minimal. In general, the departments in which the staff and research workers numbered from 25 to 35 recommended a room of 150 to 200 square feet in area which could be maintained at a temperature from 0° to 5°C and a smaller room or compartment which could be kept from —5° to —20°C. In most cases the latter room was approximately half the size of the former.

Services which should be supplied to the cold room include electricity, water (in room above 0°C), vacuum lines and adequate drains. Sufficient table space at one end of the cold room should be provided for adequate working space and setting up apparatus. The most common complaint concerning the cold rooms now in operation was that the working space for centrifugation, filtration, etc. was inadequate. Another laboratory suggests that a temperature recording machine on the outside of the cold room would be a distinct advantage. One report comments that a cold room which must be shared by a large group of workers is difficult to keep in order, since materials tend to accumulate. The suggestion was made that the available storage space be divided into lockers provided with locks to be assigned to individual workers. Another laboratory having similar trouble in keeping order prefers to buy a number of deep-freeze boxes, which can be placed in private laboratories for storage, and thus allow for more working space in the cold room.

There appears to be a wide difference of opinion whether or not a room which could be maintained at a constant temperature between 20° and 40°C is a convenience or a necessity. One laboratory reports that it has dismantled such a room because it was not used sufficiently. Many stated that, although such a room was a great convenience, its function could be taken over by large incubators or constant-temperature water baths. Fifteen laboratories, nevertheless, report that they have such rooms in operation, with the size varying from 50 to 100 square feet in area.

In addition to cold rooms and constant-temperature rooms, several other rooms designed for special purposes are of great importance. A space for a shop with a small area set aside for glassblowing must not be omitted. Some of the reports from groups who are engaged in the building or planning of new laboratories indicate that a special room for large-scale preparations is under consideration. Since many of our quantitative methods or isolation procedures require purified organic solvents, many of which are flammable, a room for the purification and redistillation of such solvents would seem a necessity. This room could serve as the storage center for the equipment necessary for such work and should be made as nearly fireproof as possible. A fireproof vault for the storage of flammable solvents is required by the fire laws of many states. Several correspondents considered a fireproof, floodproof room for overnight reactions to be essential. Others have suggested a special room for microanalyses. Although there seems to be a tendency to place analytical balances for research workers in utility rooms or offices close to the laboratory (See figure II.16), there is still much to be said in favor of a room apart from the fumes of the laboratory for analytical balances.

In planning space for biochemistry in a new building, a room for the cleaning and drying of apparatus must be taken into consideration. In certain types of research in which large amounts of glassware are used, the saving involved in a central cleaning room, operated by a conscientious worker, is invaluable. Relatively simple equipment can be used, or, if funds permit, more expensive and more permanent equipment can be available. In one research laboratory the washing room contains a "Duriron" kettle about 30 to 36 inches in diameter for bichromate-acid cleaning solution. A perforated lead basket for glassware can be lowered and raised from the kettle by means of a crane arrangement. After it is raised from the kettle and drained the basket is moved by the crane over a lead-protected area to a large laundry tub for washing with water. The arrangement permits the washing of a large amount of equipment in a short time with the maximum of safety to the operator. Steam-heated air driers complete the equipment of the room.

A survey of the equipment used in the graduate teaching of biochemistry emphasizes the increased use of more complex physical apparatus. Each laboratory was asked to state whether or not it owned or shared with other departments certain standard pieces of equipment, and, in addition, to name any other pieces of special apparatus which were used by research workers in its departments. To attempt to list all the equipment which was named in the last category would require more space than would be justified for the present purpose. It may be of some value, however, to see what instruments are so widely used that they have become standard equipment. A comparison of the lists of such instruments with those owned by the same laboratories twenty or even ten years ago would be interesting.

With the two exceptions, all the groups that reported on the questionnaire stated they had at least one spectrophotometer in their own department and the remaining two laboratories shared a spectrophotometer with another department. In many cases, two, three or four instruments are reported in a single department. Many of these laboratories have the newer types of photoelectric instruments with equipment for use in the ultraviolet and infrared part of the spectrum. Fluorometers are also rather widely used, since 20 out of 30 questionnaires indicated that one or more of these instruments were in use in their laboratory. Mass spectrometers were reported by eleven laboratories, but in five of these groups the instrument was shared with other groups. The measurement of radioactive isotopes is done in more than 80% of the laboratories canvassed, although half of these groups were sharing their equipment with other research workers. Twenty-two of the 30 laboratories had facilities for electrophoresis studies, but in the majority of cases this more expensive equipment was used by several departments.

The writer was surprised to note that only 10 of the

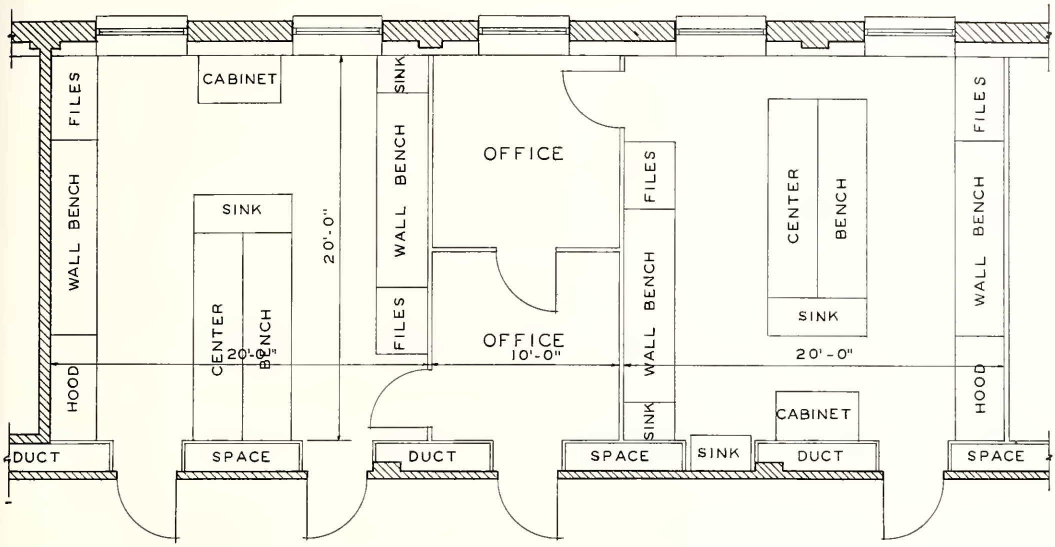


Figure II.17 Three-unit plan of Merck Research Laboratories.

30 laboratories represented in this study were doing microrespiration studies (Warburg equipment). It is doubtful if this is representative of the very general use of this apparatus in all types of biological research.

Flame photometers were reported to be in use by six laboratories and super- or ultra-centrifuge equipment by seven laboratories. Other pieces of special apparatus, which were listed as research equipment by at least three different groups, include equipment for polarographic analysis, birefringence flow studies, chromatographic adsorption work, and Craig's countercurrent extraction work.

Within the last five years many biochemical laboratories have undertaken microbiological analysis which requires special equipment, such as constant-temperature incubators or water baths for the growth of stock cultures and assay procedures, sterilization equipment which should preferably include a steam-jacketed autoclave and sintered glass bacterial filters, a sterile room for more careful handling of microorganisms, and apparatus for measurement of turbidity.

Many who responded to the request for any additional comments on the construction and equipment of laboratories not covered in the questionnaire suggested that in the building of new laboratories or the remodeling of old laboratories, more attention should be paid to the provision of safety facilities. Adequate showers, fire blankets and fire extinguishers were most commonly mentioned. The construction of research laboratories so as to provide two readily accessible exits is a desirable feature from a safety standpoint, as has been pointed out previously (figures II.16 and II.17).

It is hoped that this summary of ideas taken from the questionnaires returned by representative laboratories from all parts of the country will be of some assistance to those who are planning new laboratories. The broader aspects of the problems of construction which involve the integration of space allotment between various departments have not been considered. It is obvious to anyone who has taught biological chemistry in a medical school that there are many laboratory experiments which would be more effective if carried out in conjunction with other departments, such as physiology, pharmacology and bacteriology. Educators in the medical field should look forward to the time when there will be a better correlation in the course work in these departments and they can plan facilities for interdepartmental experiments. The writer, nevertheless, does not believe that the individual groups should lose their identity in either teaching or research.

The writer wishes to express his thanks to his friends and colleagues who were so generous in their responses to the questionnaire. Special thanks is due to those who supplied additional data beyond that requested.

9

THE CHEMICAL ENGINEERING LABORATORY

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In the past, chemical engineering laboratories have been housed in practically every conceivable type of unused space that happened to be available. Almost all of the older departments started out in the basement of a chemistry or engineering building in space that was originally intended for storage or for other types of engineering equipment. Many of the newer departments have had to be satisfied with unused space, annexes or temporary buildings. Quite frequently the apparatus that was installed in such make-shift housing was obtained to fit the available space and headroom rather than to teach a particular phase of chemical engineering. Different methods of laboratory instruction were used, at least some of which were dictated by available equipment and facilities, but it is to the credit of the pioneers in this field that in most instances a sound training in fundamentals was achieved in spite of, rather than because of, the equipment and facilities available.

These conditions were merely a part of the growing pains of an infant branch of engineering that has only "grown-up" within the past generation. A much more unified concept of the type of training and facilities needed to teach chemical engineering exists today. This section of this report will endeavor to outline the requirements upon which chemical engineering laboratory instruction is based, discuss the design of required laboratories, and give some consideration to self-contained chemical engineering buildings.

The development of chemical engineering curricula in the United States has resulted in the adoption of the unit-operation method of instruction in which unit operations common to a variety of industries are studied in considerable detail. Courses involving unit operations form the core around which these curricula are built. A student receiving a chemical engineering degree is expected to be familiar with all the factors affecting the more common unit operations and to have had some actual experience in the use of equipment that would ordinarily be involved in their industrial application. In order to provide such experience and to provide equipment capable of obtaining experimental data that clearly illustrate fundamental principles, most chemical engineering departments include a unit operations laboratory. Such a laboratory requires many special features not encountered in other university laboratories.

Chemical engineering curricula also usually contain a relatively large amount of other laboratory instruction since the fundamentals of chemistry, physics, and mechanical and electrical engineering must be covered. Laboratories for this type of instruction are designed for the needs of the particular subject involved and do not normally require special provisions for chemical engineering students, although some of them may be located in chemical engineering laboratory buildings. Such laboratories are discussed in other sections of this report.

Most of the equipment in a unit operations laboratory is of the size and type that is frequently encountered in a pilot plant and in many instances is actually a small-sized replica of full-scale industrial equipment. The size and type of the equipment are not as important as its usefulness in providing accurate experimental data to enable a student to make his own analysis of the factors affecting a particular operation, and the design of such equipment should be governed by the requirements of flexibility and accuracy of the experimental data and not by appearance or size. In order to meet these requirements, however, the size of the equipment is usually such that the quantities of materials handled are measured in pounds and gallons and not in grams and cubic centimeters. Thus, the size of the equipment that must be provided is one of the factors that influences the design of chemical engineering laboratories.

The laboratory should provide facilities for the study of six to ten unit operations by undergraduate students. Those most frequently studied are:

Fluid flow
Heat transfer
Evaporation
Distillation
Absorption
Filtration
Drying

Depending on the particular methods of instruction or the interests and experience of the staff, it may be desirable to substitute or add one or more of the following operations:

Extraction
Adsorption
Mass transfer
Air conditioning
Crushing and grinding
Size separation

In at least half, and preferably more, of these unit operations it is desirable to have the student obtain experimental data from more than one type of equipment to illustrate different phases of a particular unit operation. Thus fluid-flow equipment should provide for the flow of gases and liquids, more than one type of heat transfer should be illustrated, etc.

Most chemical engineering laboratories also provide equipment for the study of unit processes in which a chemical reaction rather than a physical operation may be carried out. Although such processes may be operated on a scale which will involve only glassware, it is customary to provide small kettles of various types, ovens and dryers, furnaces, autoclaves, etc., which are normally not readily adapted to the instruction in unit operations but are extremely useful where chemical reactions are to be studied. In many instances some of the equipment provided for carrying out unit operations will also serve for part of a unit process. A filter press, for example, may be used to study the mechanics of filtration or it may be employed to recover a particular solid from a liquid. Unit process equipment, such as small kettles, is also particularly useful for research purposes.

The almost universal use of the group method of instruction also should be considered in the design of a unit operations laboratory. Most equipment of this type cannot be operated satisfactorily by one or two men, particularly if simultaneous readings of different instruments are desirable. In addition, it is frequently necessary to analyze samples, calculate data, and make weighings while the experiment is in progress. These requirements usually result in the inclusion of four to eight students in a group for the operation of a particular experiment. In schools having large enrollments it may be necessary to have more than one group working in a single laboratory section. Even in cases where a fixed enrollment eliminates such a possibility, it may be required to utilize staff time more efficiently or to avoid scheduling difficulties. The use of the group method requires careful layout of equipment to provide ample working space, particularly if more than one group must operate adjacent equipment.

Research, on the other hand, is usually carried out by individual workers or, at the most, two students working together. It is very desirable to provide the research worker with individual laboratory table space as well as a small study desk or room in an office. The most important facilities required by the research worker, however, are auxiliary equipment, instruments, services, and the general requirements of flexibility of building design, layout and equipment. These factors will be discussed in more detail later.

DESIGN OF UNIT OPERATIONS LABORATORIES

The fundamental concepts of utility and flexibility should govern the design of a unit operations laboratory, but the specific considerations of number of students to be accommodated, type of instruction to be provided, general architecture of the building to house the laboratory, maximum permissible cost, and some allowance for expansion are important factors that influence the design. The number of students to be accommodated, both for undergraduate laboratory work and research, will have an important bearing on the space requirements. As mentioned previously, the group method of instruction is usually used in the unit operations laboratory, so that there should be ample room around equipment and an easy means of communication between operating levels.

The type of instruction to be offered also has an important bearing on the general laboratory requirements. Although laboratory work covering the most frequently encountered unit operations is usually the most important requirement, some institutions also require laboratory courses in unit processes, chemical preparations, and even occasionally operate more or less complete miniature chemical plants. This type of equipment requires a considerable amount of floor space but does not require very much head room.

The architecture of the building in which the unit operations laboratory is housed may have an important effect on the laboratory design. The building should be functional, but most university campuses do not permit complete functionality. Almost any engineer, asked to design a completely functional building to house a unit operations laboratory, would specify a two-story box-like structure. Distillation columns complete with operating platforms would protrude through the roof. Drum storage would be located outside, and pipe and structural steel storage would probably be located in an unheated, sheet metal shed with a convenient scrap bin attached. Two or three adjacent one-story sheet metal sheds could be provided for high-pressure laboratories or other research that needed to

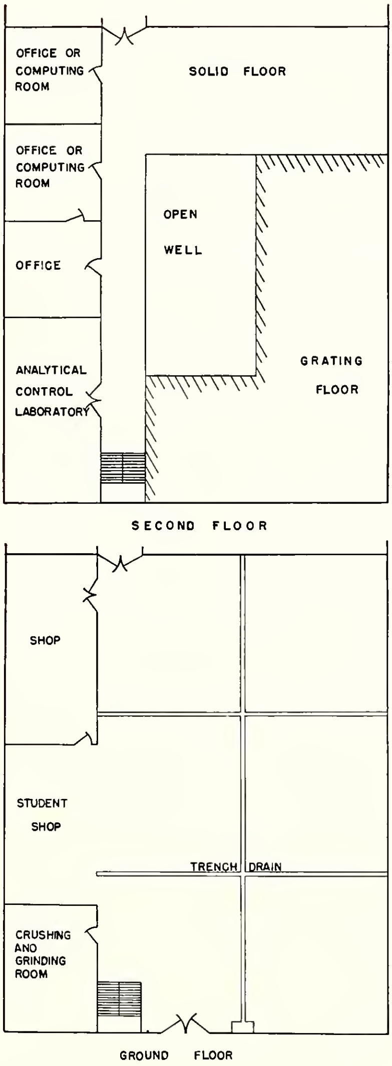

Figure II.18 An approximate composite of the floor plans of 25 existing unit operations laboratories. (W. L. Kranich, Chemical and Engineering News, 1948)

be isolated. The structural steel work would all be left exposed for ease of mounting of equipment and all walls might be left unfinished. Such construction would meet the requirements of utility and flexibility and undoubtedly would also provide the maximum floor space for a minimum cost, but any attempt to get it approved by the building committee of most universities would be a waste of time. A more realistic approach would be to admit at the outset that a university campus is not a factory site. Green lawns and ivy covered buildings do not blend with dirty drums and sheet metal sheds. However, the restrictions imposed by the required architecture need not be severe. The main requirements are usually that all equipment and storage be housed within the building, that there be a minimum of protruding structures on the roof, and that the building be of a substantial construction that does not clash too seriously with the type of architecture that may exist on the rest of the campus.

The extremely high cost of laboratory construction makes it necessary to consider space requirements very carefully and to make the laboratory as compact and efficient as possible. These conditions may also make it impractical to make adequate provision for future expansion without additional construction. It is almost impossible to generalize regarding the least objectionable sacrifices that might be made to meet a definite limit on the over-all cost. Local conditions, the method of instruction employed, the content of the curriculum, the number of students to be accommodated, the type of architecture, and the materials of construction are the most important factors influencing the cost. However, several methods of economizing are frequently suggested. The most commonly encountered are: leaving the walls unfinished, using lanterns protruding through the roof to house all tall equipment, cutting down the width of corridors, eliminating small laboratories to save wall space, and providing for only a minimum distribution of services.

Reduction of the cost of construction at the expense of flexibility should be avoided. In general, this means that adequate floor space should be provided even though partitions and walls are omitted; adequate service lines should be brought to the laboratory, even if they are not properly distributed; shop room and equipment should be ample; and there should be some provision for easily moving heavy equipment. Weber* sums up the general considerations very ably: "The fundamental ideas of utility, flexibility, and cost should be kept in mind not only in the construction but in the operation of any chemical engineering laboratory. Every attempt should be made to prevent the laboratory from becoming static. To this end the design should include provision for periodic modernization. All equipment should be considered of a temporary rather than a permanent nature. It should be so installed that it will be readily removable, thus making space for newer, more useful units."

Based on inspections of over 25 existing chemical engineering laboratories, Kranich† has presented a composite design which is an approximate average of existing laboratories, but not necessarily an ideal arrangement. The floor plans for such an average laboratory are given in figure II.18. It is rectangular in plan, approximately 60′ 0″ by 75′ 0″, two stories high and provides for a section having headroom of 27 feet. A balcony on four sides surrounds a central well served by a traveling crane. Portions of the balcony are floored with sections of removable grating to provide working platforms around tall equipment and to make a crane more useful. The main service lines are run under the second floor corridor and along the wall where gratings are employed. Windows are provided on at least two sides and fluorescent lighting is used both on the ceiling and under the balconies. The main floor is sloped toward a trench drain, covered by removable gratings, extending centrally along the full length of the laboratory and provided with branches to shorten the path of drainage over the floor. Provisions for a shop, control laboratory, and other special rooms may be made as indicated in figure II.18.

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* Weber, H. C., J. Chem. Education, 24, 341 (1947).

† Kranich, W. L., Chem. and Eng. News, 26, 1830 (1948).

In agreement with this composite picture of the general plan of a unit operations laboratory, the ideal shape is probably rectangular, at least part of the floor area should be served by a crane, one or two balconies should be provided, and there should be at least a small section of the laboratory where clear headroom of 30 feet can be obtained. Service lines should be well distributed, trench drains in the main floor are a necessity, illumination should be adequate, and space should be provided for at least a shop, control laboratory, computing room and general storage.

A rectangular laboratory provides for the most efficient use of space, regardless of the balcony arrangement. The ratio of length to width is not too important, but it would normally vary from 1.5 to 2.5. The long, relatively narrow shape allows easy segregation of types of equipment, permits several groups to operate at the same time, and makes for less interference between graduate research and undergraduate instruction. It also makes it relatively easy to service the area with a crane having a reasonably short beam, and a central drainage trench on the main floor with occasional branches provides excellent drainage facilities.

The over-all height of the laboratory should be considered carefully. If there is need for a number of research laboratories or other space, three full floors, providing a clear height of 35 to 40 feet, can be installed without an excessive increase in cost since a large number of auxiliary rooms can be located along one side of the main laboratory. If two floors are all that are required, a total headroom, clear of the crane, lights and services, of approximately 24 feet is about all that can be obtained. This should be an absolute minimum, and even 24 feet will restrict the size of tall columns and does not permit the use of barometric condensers. Two methods can be used to obtain additional headroom over small areas. A small penthouse or lantern can be extended through the roof to provide additional height over part of the laboratory. This method prevents the use of a crane over an area where it would be particularly useful for moving feed drums and mounting equipment. It also requires the installation of special stairways and operating platforms in the lantern. The extension of the lantern above the roof may interfere with the architectural design of the building and for that reason be impossible to install. The other method involves the excavation of a small well or sub basement. This construction requires special sewer lines for drainage and can be hazardous if flammable or poisonous vapors are handled in equipment installed in this location. Any leaks would release vapors that are usually heavier than air and would collect in the recess. If this method is utilized, special ventilation should be provided to exhaust vapors from the lowest point.

There are many possible variations in the location of balconies around the main well. Wade and Champlin* give a good description of a laboratory in which three balconies surround an open area on all four sides. This design is preferred by many and is frequently encountered. Possible objections involve difficulties in proper lighting of the main well, narrow balconies, and, if corridor space is left around the periphery of the balconies, there is no available wall space for mounting equipment. If the crane serves only the central area, the width of the balconies at one end should be different to permit the crane to pick up or deposit equipment on any balcony level so that it can be skidded to its proper location. In many instances removable gratings are used in the balcony floors. Services can be run along the outer walls or under the outer periphery of the balcony.

The other extreme in balcony arrangement places the balconies along only one side of the open area. This method is illustrated in figure II.19, which is an elevation through the unit operations laboratory shown on the building plans in figures II.22 and II.23. This method permits a large window area along the bare wall of the well for daylight illumination, and easy horizontal and vertical distribution of services as shown in figure II.20. The horizontal distribution lines can be run at any desired level with risers extending upward and downward. The particular installation illustrated carries the horizontal lines at the top of the wall, with vertical lines extending downward, as shown, every 20 feet. Other distribution lines are run under the corridor part of the balconies and are extended horizontally under the balconies. (See figure II.19.) The same services can very easily be distributed to research laboratories at the balcony level by coming up from the floor below. This balcony arrangement leaves a large wall area for mounting equipment, and provides one wide balcony instead of two narrow working areas. While balconies on two or four sides, with a relatively narrow working space, may be preferable in an industrial laboratory, the wider space provided by the single balcony is a distinct advantage when groups of students are running an experiment. In the arrangement illustrated, the crane can be run over each bay (between columns) on a fixed beam extension. With removable gratings, this permits picking up equipment from the basement level

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* Wade, W. B. and Champlin, L., Chem. Eng. News, 25, 2629 (1947).

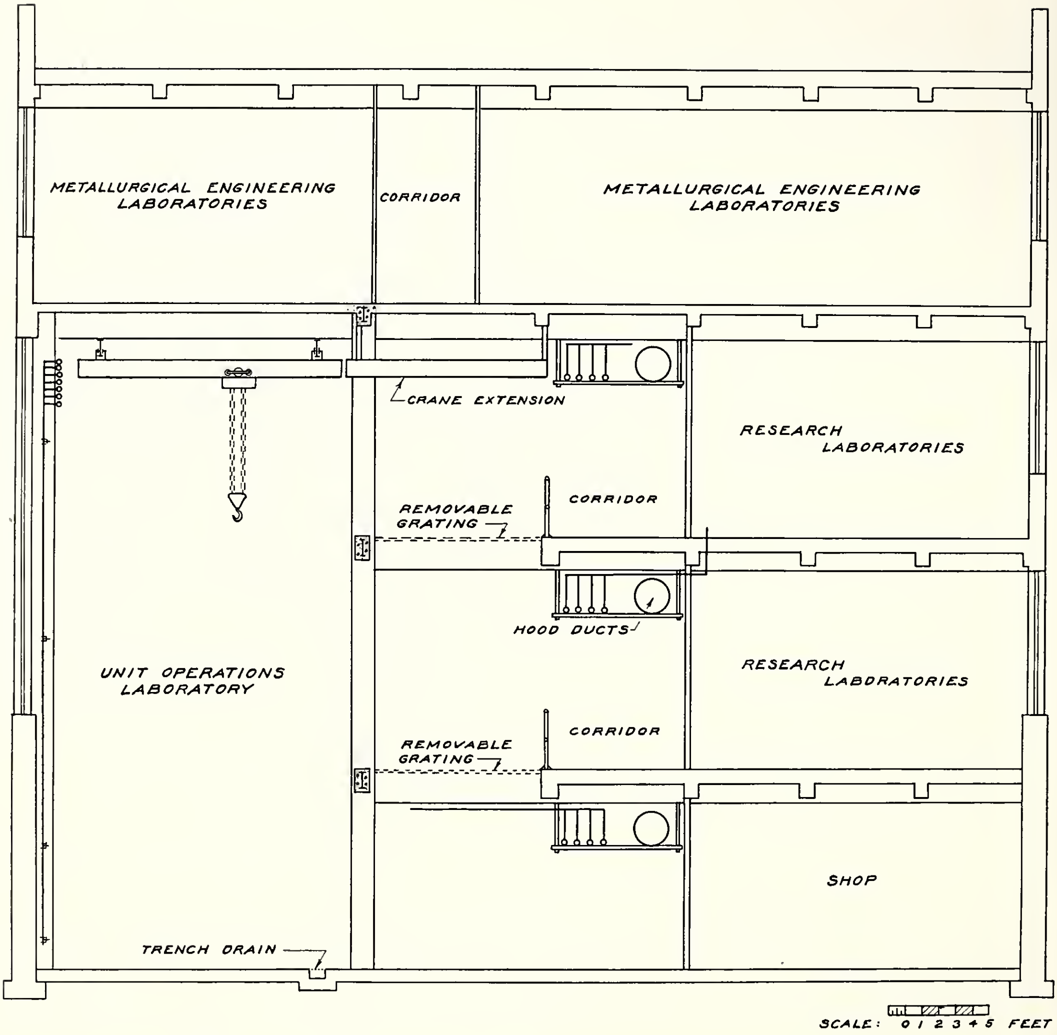


Figure 11.19 This diagram shows a cross-section of a large laboratory having balconies along one side of an open bay. Note methods of distributing services.

and setting it down on either balcony, provided equipment is not in the way. A possible alternative would be to extend the first balcony across one end of the main well with approximately a 12-foot width, and provide a 6-foot extension of the second balcony above it. This would permit the crane to place equipment at any level on the end balconies from where it could be skidded or rolled into place on the side balconies.

Another alternative arrangement of the laboratory should be mentioned, in which there are two or more solid floors with one or more open areas 50 to 100 square feet in area extending through the solid floors. Tall equipment is then installed in these spaces. Such an arrangement undoubtedly provides maximum floor area for a given cubage and reduces the cost per square foot of total floor area, but may restrict the installation of tall equipment. It does not permit the use of an overhead crane and therefore requires a large freight elevator. This plan interferes with the student's clear visualization of tall pieces of equipment and interferes with communication between floors while taking data. Service distribution is also somewhat more difficult although several horizontal runs can be installed along the ceiling of each floor and extended downward to individual pieces of equipment. Tall equipment is rather difficult to install. There should be some means of handling pieces approximately 20 feet in length, but this may be difficult if the well areas are small.

These balcony arrangements are by no means the only ones encountered. Laboratories have been constructed with balconies on two or three sides of an open area, and it is not unusual to find various combinations of gratings and solid-floor balconies. An excellent illustration of a compact arrangement is shown in figure II.21. In this case, a small open well is provided at one end of a balcony provided with removable gratings. A solid balcony is also used for part of the main working space. The crane operates over the open well and the removable gratings and it can be moved over the solid-floor balcony by means of an extension beam. Such arrangements usually have special advantages with respect to the rest of the building or are a compromise between total desired floor space, headroom, maximum allowable cost, and building architecture.

In most cases the balcony height is governed by the design of the rest of the building. Special operating platforms are then built to provide working space around equipment. If plenty of headroom is available, equipment may be mounted in such a way that operations can be carried out at fixed balcony levels without installing special operating platforms. In order to facilitate this method of installing equipment, some designers advocate balcony heights of 7 to 9 feet so that controls and instruments may be reached without the use of ladders or platforms. Such a balcony height, however, ordinarily would not coincide with floor spacing in the rest of the building and does not provide for auxiliary rooms around the balcony.

The use of an overhead crane has been mentioned several times without considering its size. The capacity of such a crane should be at least two tons, and the length of the traveling beam should be considered very carefully. The width of the main well in the laboratory will ordinarily be from 18 to 25 feet, depending on the column spacing, while the over-all width including balconies will ordinarily be 40 feet or over. If the crane only services the well, the beam will usually have a span of about 20 feet. If the columns supporting the balconies do not extend to the ceiling but are stopped at the upper balcony level, the crane can service the entire area but the traveling beam will have to span a much greater width, and consequently will have to have a much greater depth. A 2-ton crane spanning 19 feet requires nearly 30 inches of clearance below the ceiling beams and the hook clearance required is nearly 6 feet. This means that all equipment must be at least 30 inches below the ceiling or the crane will be blocked, and special slings must be arranged to lift closer to the ceiling than 6 feet. If the span is doubled, these required clearances may take up 20% to 30% of the total headroom. For this reason, crane extensions, monorails, or temporarily installed chain falls are frequently used over balconies and the span of the traveling crane kept to a minimum.

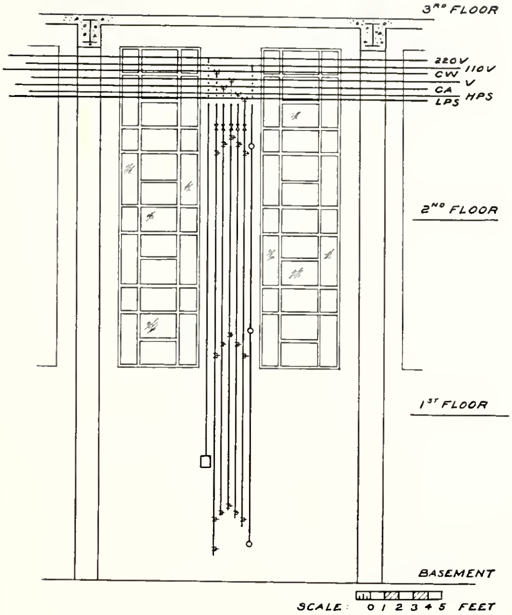
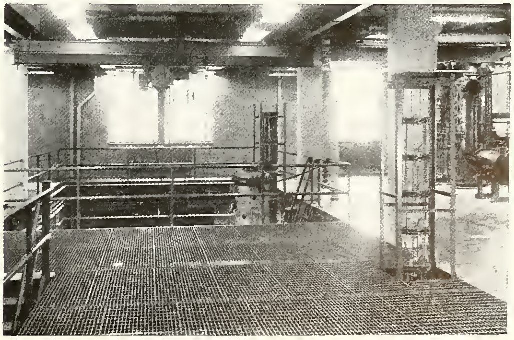


Figure II.20 This diagram illustrates the method of distributing service lines along open wall of the laboratory of figure II.19. The vertical risers come down every twenty feet.

Means of mounting equipment on walls and columns should be provided for in the design of the laboratory. If the structural steel of the building can be left exposed, additional supports can be welded or bolted to columns or beams as required, provided such installations do not appreciably weaken the structural members. However, most building codes require that the

Figure II.21 View of a unit operations laboratory showing both gratings and solid-floor balconies (Courtesy Northwestern University).



structural steel be insulated with concrete or building blocks. In this case, continuous channels, or short sections at 3 to 5 foot intervals, should be welded to the columns in such a manner that they protrude through the insulation. This provides a convenient method of mounting equipment on the columns. If the laboratory design is such that working wall space, free of service lines, is available, brackets or imbedded T-slot channels should be mounted in the wall at suitable intervals. Light equipment can then be supported from the walls. Although a large percentage of these types of mounting brackets is left unused at any one time, they do provide maximum flexibility and permit changes to be made without interfering with building construction or finish. The natural tendency to avoid replastering, concrete repairs, and repainting may often be a major deterrent towards alterations in, or relocation of, equipment. If the original design can be such that flexibility is provided without requiring even minor alterations in walls, ceiling or floors, it should be achieved even at the cost of some additional expense.

Open-trench floor drains should be installed in the main operating floor. These trenches are normally 6 to 12 inches deep and 6 to 10 inches wide and are covered with cast-iron gratings. Two general arrangements are in use; one has a central, main trench with branches extending outward to the sides of the laboratory; the other provides for a drain extending around the laboratory at a short distance away from the walls. Either method may be used but the equipment should be so installed that horizontal runs of drain pipe along the floor can be avoided. The effective use of these drains requires that the floor have a slope of ⅛ to ⅝ inches per foot. If the construction is carefully done, the lower figure is satisfactory, but a conservative slope is ¼ inch per foot. The grating covering the trench should be in sections of various sizes so that openings of various lengths may be provided as needed.

Auxiliary Laboratories and Rooms

The nature of the experimental work carried out in the unit operations laboratory requires the quantitative analysis of samples. For this reason it is customary to locate a small analytical laboratory adjacent to the main unit operations laboratory. If proper supervision can be maintained, this room should be completely equipped with all of the most frequently required instruments and glassware, as well as common analyti-

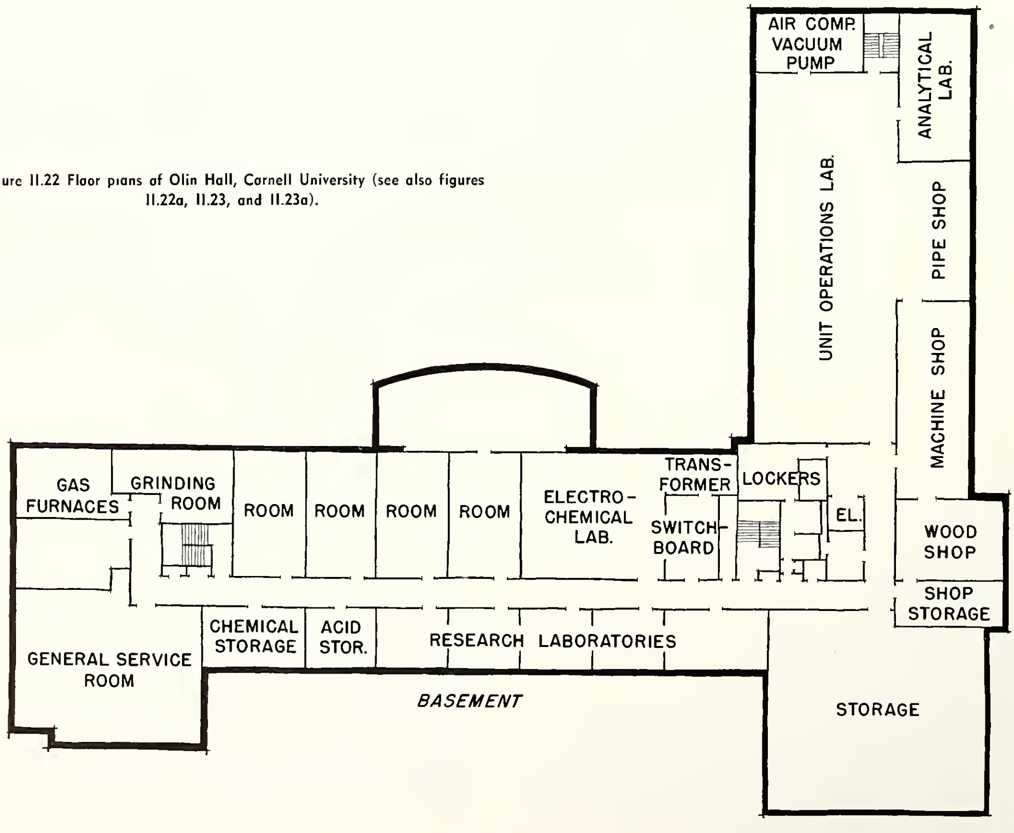


Figure 11.22 Floor plans of Olin Hall, Cornell University (see also figures 11.22a, 11.23, and 11.23a).

cal reagents and standard solutions. If it is possible to operate such a laboratory, it is very desirable, as research students can also use it for analytical work with an appreciable saving in time. Such a laboratory will more closely resemble a small industrial control laboratory than a conventional university chemical laboratory, and may contain a considerable number of instruments that are left in place.

The use of the group method of instruction makes the provision for a computing room very desirable. It need only be equipped with large tables and chairs but is even more useful if it contains blackboards, handbooks, a computing machine, and perhaps even typewriters. Such a room facilitates the group calculation of the experimental data and the preparation of the skeleton of the individual's report on the experiment while the equipment and staff are readily accessible for checking details of construction and operation.

Since a great deal of research work can be carried out in standard glassware or in small, specially constructed, easily mounted glass or metallic equipment, practically all chemical engineering laboratory buildings provide for small test-tube and bench-scale research laboratories. They are usually more or less standard chemical laboratories designed to accommodate two to four men. In some instances, larger groups are accommodated, but the trend seems to be towards the smaller rooms. Such laboratories are completely discussed in other sections of this report.

Small rooms should also be provided to isolate noisy, dirty, or hazardous equipment. In connection with service facilities, an air compressor and a vacuum pump will be required to serve the unit operations laboratory. Since a considerable amount of noise results from their operation, they should be located in a separate room. Crushing and grinding and size separation equipment should also be located in a separate, well ventilated room not only to reduce the dust nuisance, but also to facilitate cleaning and allocation of responsibility for keeping this equipment clean. Furnaces, other than small laboratory models, should also be in a special room provided with excess ventilation and means for exhausting gases. Hazardous equipment, such as that used for high pressure work, should be located in special rooms provided with all required safety features.

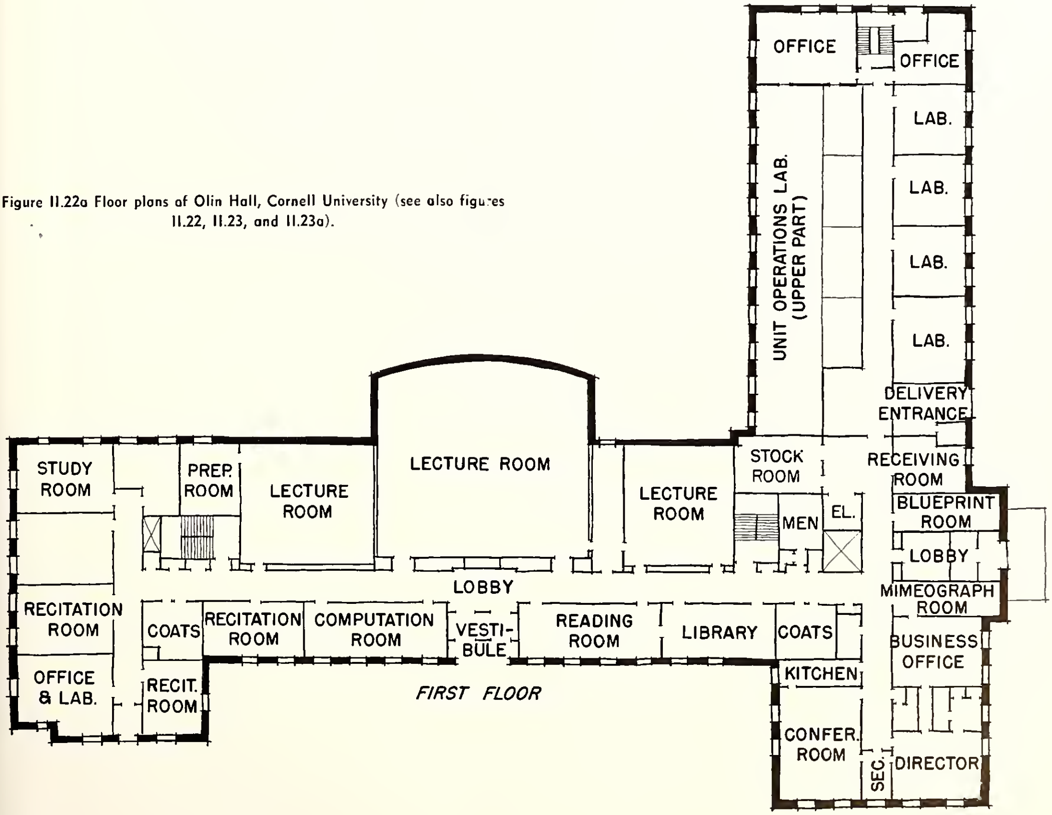


Figure 11.22a Floor plans of Olin Hall, Cornell University (see also figures 11.22, 11.23, and 11.23a).

Shops

Facilities for shops should be provided in the vicinity of the unit operations laboratory. It is desirable to provide for two separate shop areas, one for general student use, and a restricted area under the supervision of one or more full-time mechanics. There is no general agreement on the extent of student shop facilities, but as a minimum, pipe-fitting equipment, drill presses, and a work bench equipped with a vise should be provided. A tool check-out system from the restricted area should also be included. The main shop should contain the usual machine tools with special emphasis on welding equipment. It should also contain at least a minimum of machines for sheet metal and wood working. The layout of equipment should allow for the handling of up to 20-foot sections of pipe, particularly for cutting, welding and drilling. Ample storage space should be considered unless storage and delivery from other locations is very favorable. Over a period of years the shops will prove to be a most important asset to the laboratory. Ample room, tools, machines, supplies and good working conditions will pay big dividends, not only from the standpoint of getting and keeping good mechanics, but also in the maintenance and efficiency of the laboratory equipment and the general quality of the laboratory and research work.

General Storage Facilities

In addition to the storage of supplies for the shop, most chemical engineering laboratories require storage space for instruments and other special apparatus, motors, pumps, etc., all of which should be kept clean and dry. Irrespective of the methods employed for handling such equipment, the storage room should be located where close supervision is easily accomplished. This type of equipment should not be stored in a remote basement room because it is usually checked in and out frequently and careful supervision is required to keep it clean and in good working order.

If the chemical engineering laboratories are located in the same building as, or adjacent to, the chemistry department, it may not be necessary to maintain a stockroom to dispense chemicals, glassware, and general laboratory equipment. If the chemical engineering

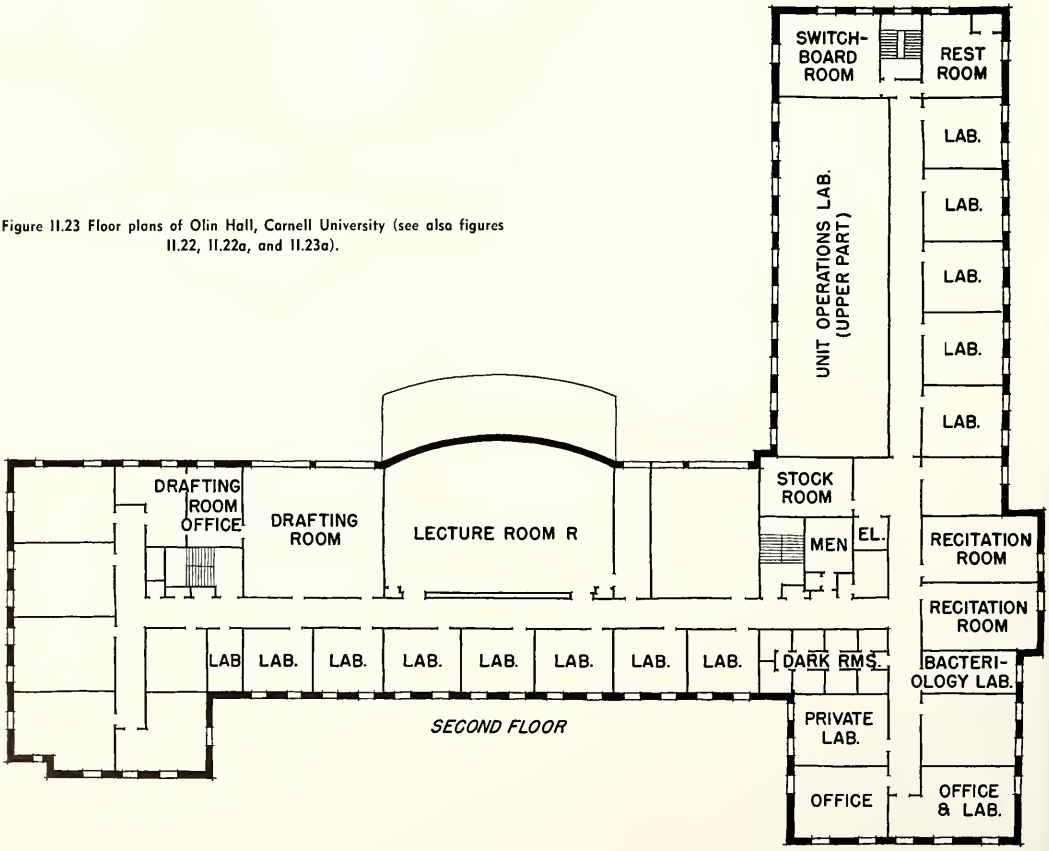


Figure 11.23 Floor plans of Olin Hall, Cornell University (see also figures 11.22, 11.22a, and 11.23a).

department is not in the same building with the larger chemical stockrooms, a room should be provided from which stockroom items may be issued. The size of the storage space to be provided should vary with the ease with which stocks can be replenished.

In almost all cases, however, it will be found that some chemicals will be used in much larger quantities than is the case in the general chemistry laboratories. This is particularly true of some acids, bases, salts, and volatile, flammable liquids. Special provisions should be made for the storage and proper handling of these chemicals in large quantities. Drums of flammable liquids should be stored in a room provided with the best safety features. Fire walls, automatic carbon dioxide extinguishers, door dams, explosion vents, easy exit, and the mounting of drums should all be considered in the location and design of such a room.

Experience has proven that a chemical engineering laboratory makes considerable use of drums of all sizes, small portable tanks, extra jacketed kettles, pails, and even kitchenware. Such items may be stored almost anywhere, but good housekeeping require a storage space that is out of sight but readily accessible to the unit operations laboratory or to an elevator serving the laboratory. There should be ample storage space for this kind of equipment when it is not in use so that it is not left to clutter up the floors of the laboratories.

Services

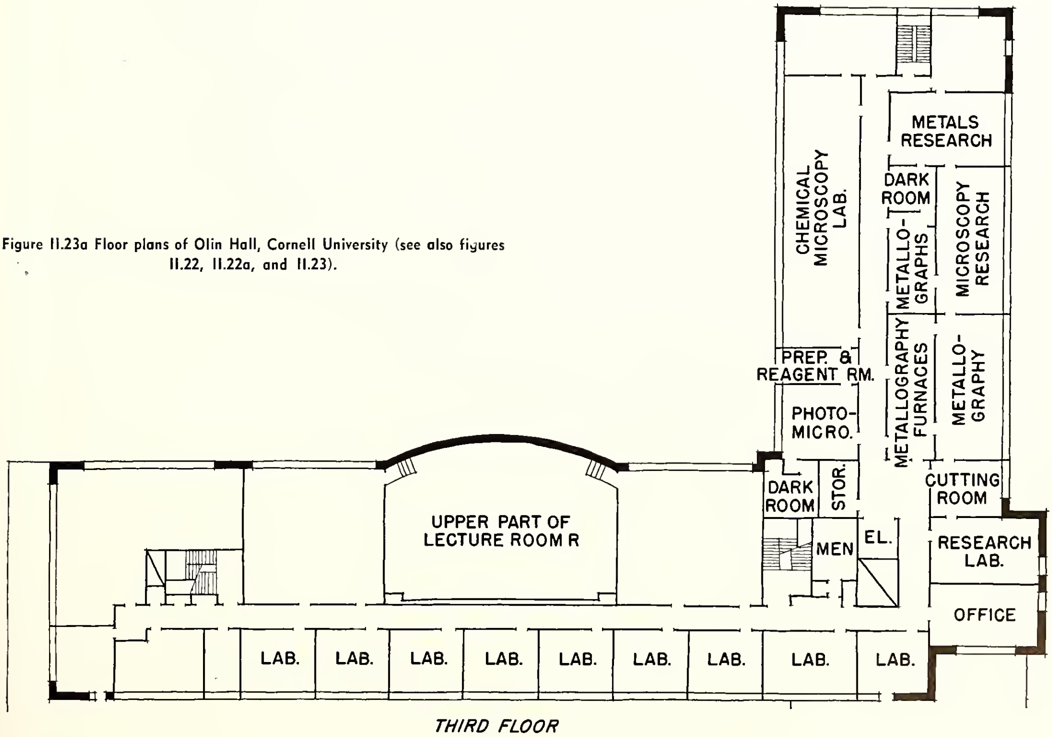
The services that are absolutely required and for which some provision should be made for general distribution, at least in the unit operations laboratory, are:

Cold water
Low pressure steam (5 to 15 pounds/square inch)
High pressure steam (50 to 100 pounds/square inch)
Compressed air
110 volt, single-phase electricity
220 volt, three-phase electricity

Provision for at least limited distribution of gas, vacuum, DC electricity, and hot water should also be included.

If it is necessary to economize on the installation of large capacity lines for the general distribution of these

Figure 11.23a Floor plans of Olin Hall, Cornell University (see also figures 11.22, 11.22a, and 11.23).



services, lines of ample capacity should at least enter the unit operations laboratory. Since this laboratory is usually of open construction, larger lines or loops can be installed later without going through or removing walls, but water and steam lines into the building and the lines to the unit operations laboratory should be very generous in size. Transformer capacity and conduits to the laboratory should also be more than ample. There are very few chemical engineering laboratories over ten years old that have not had to make major revisions in order to provide increased capacity for services, particularly in regard to inlet and main distribution lines.

While 50 to 100 pound steam would not be considered to be a high-pressure service line in an industrial plant, it is probably enough for most university laboratories. It permits the use of 150 pound piping and valves, and electrical heating can usually be used for higher temperatures.

It is difficult to suggest capacities for service lines since they should depend on the number of pieces of equipment in simultaneous operation, but careful consideration should be given to the capacities of main lines.

BUILDINGS DEVOTED TO CHEMICAL ENGINEERING

In some cases it will be found advisable, and possible, to provide an entire building for instruction and research in chemical engineering. The design of such a building would normally be influenced by the space requirements of the unit operations laboratory as well as several smaller laboratories, and it would also provide lecture rooms, recitation rooms, offices, storage space, and should include a convenient method of distributing service facilities. Many of these features, as well as details of building construction, are covered in earlier sections of this report and the design of unit operations laboratories has been discussed here in detail, but some mention should be made of general requirements. Weber* has also discussed some of the general problems involved in the design of a chemical engineering building.

The design of the building should be determined primarily by its function. Due consideration will usually have to be given to the external appearance of the building, but concern for the external aspect should not be allowed to result in a design unsuited to the function of the structure, or to increase the cost of construction unnecessarily. Since the principal function of a chemical engineering building is to provide laboratory space for instruction and research, any attempt to make the external appearance match libraries, museums, or buildings devoted entirely to classrooms, will usually seriously interfere with the functional design of the interior.

The design should permit the greatest possible elasticity in the future use of the building. In any field of science the method of instruction and the available equipment is subject to continuous evolution. Within a few years relatively unimportant phases of the work may become very important; new methods of investigation will develop and new techniques will be discovered. The construction of the building should be such as to adapt it to these changing requirements. It is extremely unwise to design only for immediate needs in such a manner that all available space is occupied. Unassigned space or large rooms are particularly valuable for changing needs as they may be partitioned off relatively easily as required by unanticipated uses. Movable walls are frequently advocated for these reasons but such construction is costly and there is some question as to their use around classrooms because of their poor acoustical properties.

Those elements of the building that carry the heaviest student traffic and are used most frequently should be located on the main floor of the building close to the most convenient entrances. These elements are the lecture rooms, business offices, library, and offices of most of the professors. Such a design minimizes traffic through the building and avoids confusion. No traffic should be permitted through large laboratory rooms although more than one exit is a required safety feature.

The distribution of services should be planned so that repairs and alterations are easily made. In some buildings the service lines have been set in the walls. To get at them is difficult and expensive. Vertical runs are frequently set in double-walled chimneys; a method that increases cost of construction, and provides only a restricted working space. The most practical vertical distribution is to run the lines in the open up the inside wall of the stair wells. Building codes may prevent the distribution of gas and high pressure steam by this method, but the actual hazard is relatively small. If such lines are properly insulated and painted they are not unattractive. Horizontal distribution throughout a building is usually accomplished by running the lines at the tops of the corridors. They can be hidden from view in the main hallways by a suspended false ceiling. Such a ceiling composed entirely of removable steel panels is available and greatly facilitates alterations and repairs.

Exposed piping and conduits in a building whose principal function is to house laboratories is not objectionable, particularly if the lines are insulated and painted. It is strongly recommended that such piping be left exposed wherever possible. Although the original designers of the building may be perfectly willing to permit the opening of holes in walls and floors to make alterations or repairs to service lines, sooner or later the officials in charge of the building will object to the expense that is required for replastering, painting, etc. Particular consideration should be given to this point. It is difficult to get architects or building committees to realize its importance, but every effort should be made to avoid the placing of service lines behind solid walls. Building committees, deans, and other university officials may agree to permit frequent alterations to walls and floors at the time the building is erected, but changes in personnel, economy drives, etc., may alter this arrangement in a very short period of time. However, if the service lines are exposed, the mechanic attached to the department can usually install extensions and make alterations without added expense except for materials.

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* Weber, H. C., J. Chem. Education, 24, 341 (1947).

Provisions for receiving incoming materials and equipment should be carefully considered in the design of a chemical engineering building. Since covered trucks and trailers are usually used, even for the transportation of reasonably heavy equipment, a receiving platform at truck height is almost a necessity. Such platforms should be designed for very heavy floor loading and lead directly to an area that can be serviced by an overhead crane in the unit operations laboratory. The use of a receiving platform is believed to be preferable to the direct entrance of trucks into the laboratory. The latter method requires extremely large doors and the problem of removing heavy equipment from covered trucks is complicated since such equipment must be brought out of the truck body before it can be picked up by a crane. The receiving platform provides the most rapid method of unloading and also permits temporary storage if the laboratory or the crane is in use. If the building is more than two stories high, a freight elevator, readily accessible to the receiving platform, should be provided. Stockrooms and storage should then be located as close as possible to the elevator.

The literature contains several descriptions of buildings devoted to chemical engineering*† and some excellent criticisms and suggestions concerning buildings and facilities have been published.‡ Figures II.22 and II.23 show the floor plans for all four floors of one of the larger chemical engineering buildings completely described by Rhodes.* This building was designed to accommodate approximately 450 undergraduate and 40 graduate students in chemical engineering courses. It is L-shaped, 274 feet across the front, with a 226-foot wing. Total floor space is approximately 110,000 square feet. As the plans indicate, several large rooms were left vacant. Since the building was completed early in 1942, these rooms were almost immediately useful for various war-time projects. The development of a new metallurgical engineering curriculum has filled them since the war.

This particular building has made very effective use of cinder block construction. The inside walls of cinder blocks were merely spray painted in pleasing tints. After seven years of hard service they are still in good condition, and the rough, porous structure provides excellent acoustic characteristics throughout the building. The cinder block construction has also the advantage of permitting easy attachment of fixtures with a minimum of effort and without defacement of the wall surface.

The floor plans for a much smaller building (11,416 square feet) have been published by Vilbrandt,§ who has described the building in detail and has also commented** on the facilities provided after nearly ten years of use. Van Hook and Schmitz§§ have also published complete floor plans and elevations for a small, two-story building containing a unit operations laboratory, offices, and auxiliary rooms.

One or two miscellaneous references to building construction should be mentioned. The location of the library beneath laboratories should be avoided. Sooner or later failures in services and soil lines may be expected with the possibility of considerable damage to a collection of books and periodicals that usually is of considerable value and may even be irreplaceable. Double doors to research or special laboratories have frequently been advocated. It has been the author's experience that 42-inch "hospital" doors in place of the standard 36-inch doors are just about as useful and much more convenient as well as less expensive. Their extra width permits the easy passage of hand trucks and any piece of equipment that would ordinarily be mounted in a small, one-story room. Larger laboratories, such as the unit operations laboratory, should, of course, be equipped with large double doors.

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* Arnold, E. A., and Hubbard, D. O., Ind. Eng. Chem., Anal. Ed., 11, 675 (1939). Benson, H. K., Pacific Chem. and Met. Industries, 4, (April 1940). Bray, J. L., Ind. Eng. Chem., Anal. Ed., 12, 375 (1940). Rhodes, F. H., Cornell Engineer, 8, 5 (1942).

† Van Hook, A., and Schmitz, C. G., Chem. Eng. News, 22, 436 (1944). Vilbrandt, F. C. Ind. Eng. Chem., Anal. Ed., 11, 234 (1939).

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10

THE METALLOGRAPHIC LABORATORY

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A review of the objectives and scope of the subject matter taught in metallography in universities brings to attention the wide variance as to both content and procedure of the standard practice for the teaching of this subject. This section, therefore, will not present a complete acceptance, but only a segment of the entire picture, and will offer a basis for choice which, for individual use, must be more properly defined.

First, metallography is the study of metallic elements and their alloys, with the emphasis placed on the physical structure of the material, the changes in the structure produced by physical action and heat treatments, and the relationship of these various structures to the composition and physical properties of the material. Second, the subject is that which will be presented as a service course to various departments of the university, either separately or jointly. Third, the equipment must be general enough for the accomplishment of these objectives, yet sufficient for specialized problems of a more advanced nature. Fourth, additional facilities, such as a darkroom, x-ray room, spectrographic room, physical testing room, etc., complete with the necessary specialized items will be available for supporting use. Fifth, the plans described are for normal classes of 20 students, under instructional supervision of a professor.

Metallographical laboratory work normally falls into five general classifications: 1. the rough preparation of samples; 2. the finished preparation of samples; 3. the treatment (heat or cold work) of samples; 4. the observation of results; 5. the recording of results or photomicrography.

This spread of activity necessitates the use of equipment varying in class from the rough and gritty nature of a cut-off or coarse grinding wheel to the exacting nature of handling the finely-ground optics of microscopes and photomicrographic equipment. It is relatively improbable that all these may be properly handled in one room, and it is categorically desirable that a metallographic laboratory should consist of a series of rooms, preferably connected, and grouped around the central larger laboratory which would be used for general gathering of data and observation.

With the necessary sequential operations required in the presentation of such material, it is normal to have students working at all stages of the work. This fortuitous condition permits the multiple use of metallographic equipment and saves expense. Thus, a central room of 25′ by 40′ would be ample, with a minimum of three supporting and auxiliary rooms 10′ by 15′. The auxiliary rooms would be titled as follows: a. shop and rough grinding; b. polishing room, and c. photomicrography room. The heat treatment, if extensive etching and similar tests are to be made, could be easily taken care of in an additional room or, if less extensive, in a large general observation room. The contents of each room will be discussed individually.

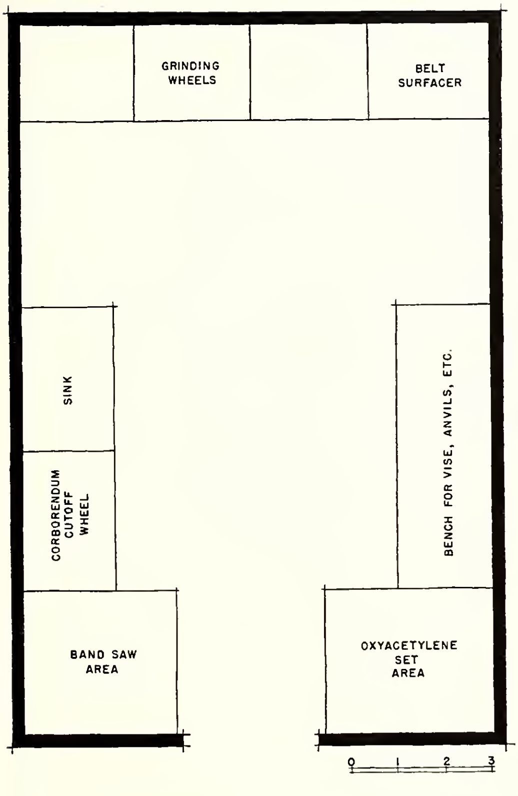


Figure 11.24 Shop and rough grinding.

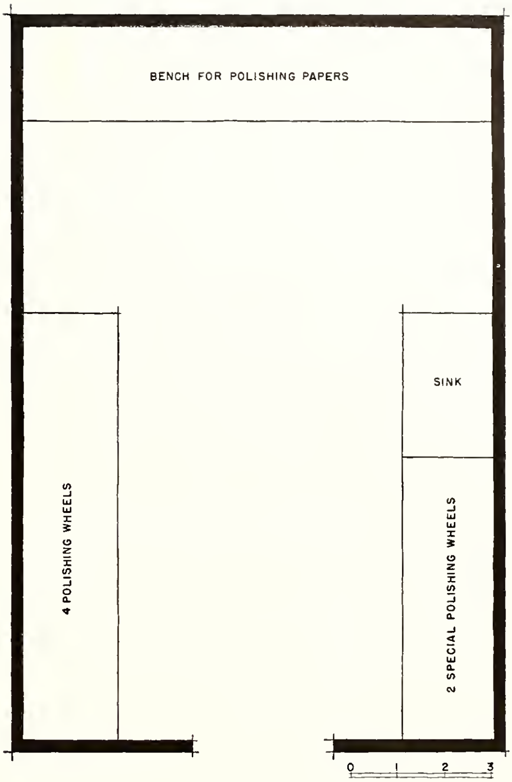


Figure 11.25 Polishing room.

Shop and rough grinding (figure 11. 24)

It is the duty of the student to utilize this room for all preparation of specimens prior to polishing wheel or lap procedures. Equipment should include a metal saw, preferably of band-saw type, an anvil, hammers, machinist's vise, hand tools, at least three pairs of grinding wheels, a carborundum cut-off wheel, and a belt surfacer. Grinding wheels should vary in both grain and porosity. The shop should be equipped with compressed air, gas, water (both hot and cold), electricity, and an oxyacetylene cutting and welding set. It is desirable that a ventilating fan be installed in this room to assist in the removal of dusts and fumes.

Polishing room (figure 11. 25)

Intermediate and final polishing of specimens should be carried on in this room. One table should be complete with glass plates and emery paper of grades 0000 to 1, and another should contain the necessary laps and horizontal polishing wheels. For a group of students of the size specified, six wheels and laps are considered ample, two for coarse work, two for fine work, and two reserved for specialty procedures such as lead lapping or extra slow speed soft-metal techniques. The tables should be complete with wash cups and there should be a sink with hot and cold water in the room. Forced ventilation may be used but is not required, as dusts should be low in amount.

Metallographic laboratory (figure 11. 26)

The function of this room is to tie together the operations of the procedure and to serve as a base for student direction and assistance. This room should contain three separate units; a heat treatment group, if not individually located, an etchant table, and a microscopic examination section. The heat treatment section should contain a minimum of two furnaces, both of which are automatically controlled, one an electric muffle type, capable of 1000°C continuous operation, and the other a small gas-fired unit of semi-muffle type with an external vent. Furnaces of approximately 6" by 4" by 12" internal size are the best compromise, if only two can be obtained. This section, or room, should also be equipped with quench tanks, which may be on casters and normally kept under the furnace bench if one room, or conveniently located if a separate room is maintained for heat treatment operations. They should be three in number, for oil, water and brine respectively. For advanced work, additional equipment for nitriding and carburizing may be provided.

The etching section of the laboratory should consist of a sink, a corrosion-resistant work surface, a shelf for reagents, and a well-ventilated hood to carry away obnoxious and corrosive vapors. The bench need not be large, a working area 2' by 4' is sufficient if accessible from both sides. The sink should be of medium size, fully corrosion resistant, and serviced with hot, cold, and distilled water. It is desirable to have a mixing type water spigot, to facilitate the control of temperature.

The microscopic examination section can vary widely, depending upon the size, shape and availability of services in the room. However, some fundamentals may serve as guides. For a group of 20 students, the use of 11 microscopes is generally sufficient; ten for student use jointly, and one reserved for student-teacher consultation purposes. Bench space, not less than 18 inches deep and three feet edge length, must be provided for each microscope; a 4-foot edge length is not excessive and, if this is to be provided at table height, stools should be supplied. Stools are preferred over chairs because of the smaller space requirements, greater ease of use, and over-all laboratory appearance.

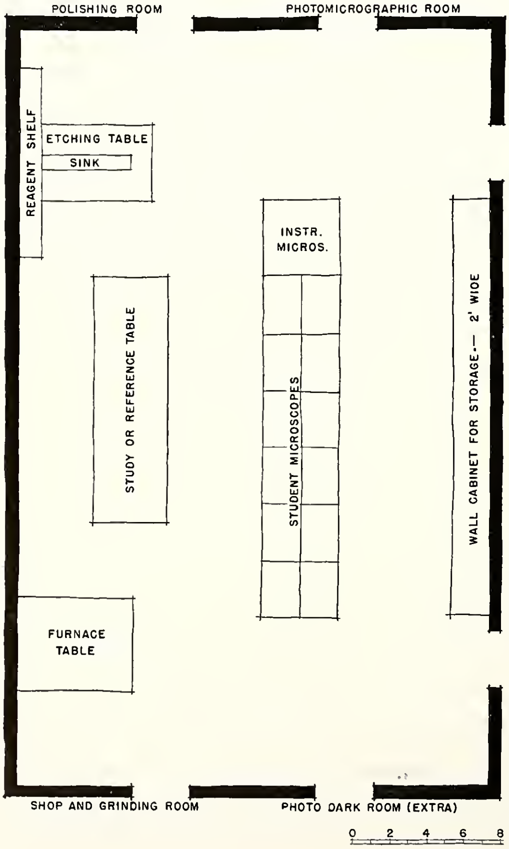


Figure 11.26 Metallographic laboratory.

Each microscope should be close to an electrical outlet to permit ready illumination. Additional space and outlets should be provided for specimen-mounting devices, special apparatus, and storage, but this need is normally small, and the design is usually arranged for maximum utility of room space. Wall charts of microstructure of S.A.E. steels are desirable, and a baloptican arrangement for showing samples for group discussion is advantageous.

Photomicrographic room (figure II. 27)

This laboratory is probably the least used but most carefully protected room of the entire group, for in it would be the most highly priced and optically delicate instruments. There should be a set of three cameras, one of research inverted-stage highly-powered type, one of medium-power table type, and one for gross photography or micrographic work. These units are all one-side working units and, therefore, may be mounted on or near the walls. However, separate mounts should be provided, as vibration is most undesirable and all units may be operating at the same time. For purposes of convenience and space utilization, hardness-testing machines may also be placed in this room. If this is undesirable, the main laboratory may be used. One Rockwell Hardness Tester is a minimum for proper instruction, and will occupy a floor or table space of about 3' by 4'.

For those wishing to install complete units for metallographic work, beyond the general or service stage, several other rooms and facilities should be provided. Radiographic and x-ray diffraction study equipment, a magnaflux system, and a spectrographic unit may all be considered as useful but highly specialized tools, and require facilities beyond the scope of this article. Moreover, if a physical testing laboratory is not available, a universal testing machine, impact testing machine, and hardness testing equipment may be combined with a set of metal-working rolls and fatigue stress apparatus to round out the program. This equipment will necessarily be supplemented with a suitable dark room provided with equipment for microphotography, x-ray, and spectrographic work, as the occasion demands.

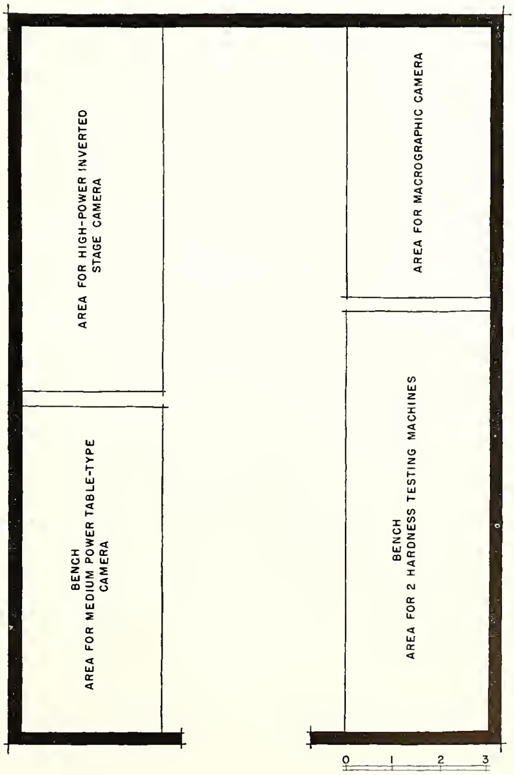

AREA FOR HIGH-POWER INVERTED STAGE CAMERA
BENCH AREA FOR MEDIUM POWER TABLE-TYPE CAMERA
AREA FOR MACROGRAPHIC CAMERA
BENCH AREA FOR 2 HARDNESS TESTING MACHINES
0 1 2 3

Figure II.27 Photomicrographic room.

Part III

INDUSTRIAL LABORATORIES

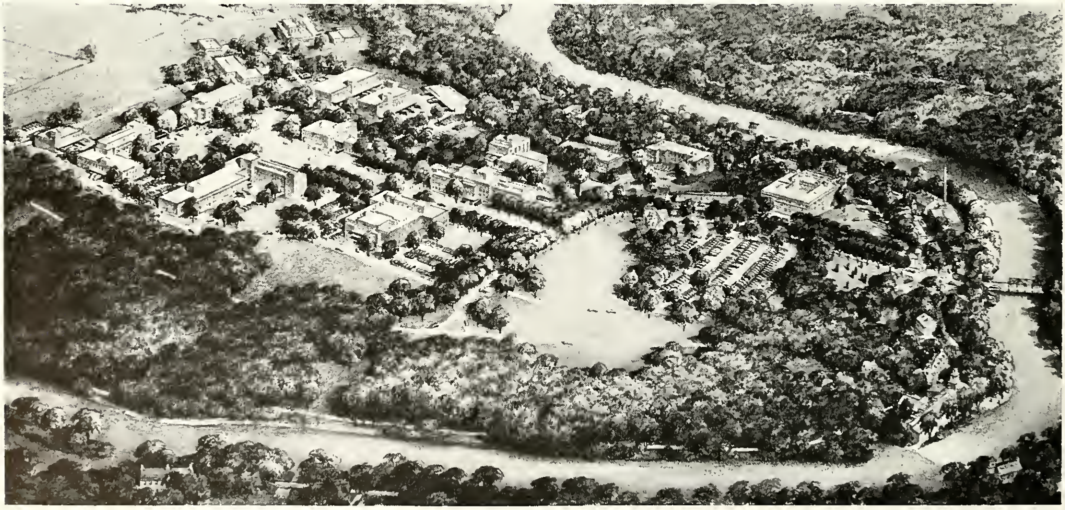


Figure III.1 Sketch by Chester Price for the DuPont Research Center, Wilmington, Delaware. Voorhees, Walker, Foley & Smith, Architects and Engineers.

1

LOCATION AND GENERAL DESIGN FEATURES

Ralph T. Walker

Voorhees, Walker, Foley & Smith, New York, N. Y.

SITE DEVELOPMENT

The choice of a new site for a laboratory development is one which obviously should be undertaken with great care, for here will be found not only the opportunities but also, too many times, the limitations to intelligent growth. The idea of fundamental planning is to create conditions which will not hamper the unknown needs of the future.

The industrial laboratory in the past has grown up either within or immediately adjacent to the industry itself, quite often as a stepchild and in surroundings which are at best opportunist in nature. The growing competition within all industry—under the realization that research is vitally necessary in these times—for the best type of research scientist and worker has brought about an appreciation that quality of working conditions and added amenities are worth the serious consideration of management. So one by one, recently, laboratories which have been completely under the factory managements' wing have become more nearly autonomous, and in sites and in buildings which create an atmosphere of unusually fine working conditions. The choice of a site, then, is playing an increasingly important part in the establishment of the laboratory center.

Frank Howard, then president of the Standard Oil Development Company, posed the problem in this manner:

1. That provision should be made for a growth of at least three times that which was presently being considered; that no obstacle be placed in regard to the future needs by present opportunism.
2. That the laboratory group finally achieve an entity and a character of its own so that it will be readily recognizable as a desirable place to work.
3. That it be surrounded by all the amenities which management and designer could foresee, because working conditions in the past twenty-five years had measurably improved and there was no reason to suppose that they would not continue to do so.

Another owner has said that all the amenities (and here quite noticeable) surrounding the working conditions in a great laboratory center did not add up to more than a fraction of 1% in yearly operational costs.

The character of a laboratory development is one generally approved of as being desirable by most residential communities on three counts: 1. it has but little nuisance value, 2. the people who work within it are of high caliber, 3. the development is responsible for additional taxes to the community. The first can be further worked out, usually, to minimize the normal aggravations.

PROGRAM OF LABORATORY REQUIREMENTS

These requirements should first be developed on net usable space factors. In general, to obtain a gross area, assume for straight office space a net of 65%, and on laboratory space a net of not more than 55%. If diagrams are made and such items as corridors, stairs, toilets, etc., are indicated, of course, the net gross can then actually be measured, but at all times added consideration must be given to the space occupied by pipe and electrical services together with the ducts for ventilation and exhausts to laboratory equipment. Generally in these considerations, the gross area has been estimated at too low a figure; this applies also to the cube, because again sufficient space allowances have not been made for horizontal distributions of services, i.e., pipe galleries and exhaust assemblies and, not least, storage facilities.

Finally, a sufficient space should be allotted to air-conditioning and ventilating machinery, for which there is no quick "rule of thumb" approximation.

Many industries have thought it highly desirable to employ a competent architect to aid in developing the program and in judging the qualities of the several choices for a site. Six of the largest research centers have taken such advice to the lasting benefit of the project. Certainly one mistake (strangely enough quite often in evidence) to be avoided is to buy a site because of its romantic or advertising interest; or (one equally in evidence) because the land is cheap. The cheapest land often carries with it the greatest development costs. In fact, all marginal land, no matter what its cost, is very likely to be the most expensive.

Visits should also be made to other laboratories. This type of survey is highly desirable. Laboratory research is not completely standardized and much can be learned in criticism of present-day working conditions.

The following check list contains elements often disregarded or considered at too late a period:

I. Management

- (a) Offices—sizes and numbers:
  1. Executive offices (private toilets)
  2. Group offices
  3. Stenographers offices—individual and pools
- (b) Reception facilities:
  1. Gate houses—number and size; employee passes (is a single employees' entrance required?)
  2. Will the personnel department require an outside entrance for prospective employees?
  3. What percentage of employees can be expected to come by bus, by private car, other means of travel
  4. Employees' parking needs; character and position of parking lot
  5. What facilities would be needed in connection with visitors' entrance such as waiting room, escorts, toilets? Comment: Here of course there is also the opportunity for a dignified display of the laboratory's work and also its relationship to its industry as a whole.

  A very careful analysis should be made of the number of employees: mapping their distribution and present living centers—the length of travel in miles and time; also the qualities of the communities in which they live, the value of their properties, etc.
- (c) Auditorium: How large a seating capacity and what are the stage requirements? Comment: Large laboratory centers require, besides the average size conference rooms, a larger room for meetings of whole departments, safety committees, scientific meetings related to industry research, etc.
- (d) Dining facilities:
  1. Cafeteria and service dining rooms
  2. Private dining rooms for staff and visitor entertainment
  3. Lunch rooms for those who bring their own lunch or who do not wish to change from rough working clothes
  4. Kitchen pantries
  5. Kitchen storage: refrigerators, garbage disposal
  6. Locker room for help—male, female
  7. Office for the dining room management
- (e) Shipping and receiving:
  1. Shipping and receiving platforms, number of trucks
  2. Space for packing and unpacking
  3. Office
  4. Mail service

(f) Storage facilities:
  1. Central storage
  2. Branch services, storage for departments
  3. Self-service storage
  4. Chemical storage bulk material
  5. Supplies—stationery, etc.
  6. Glass storage
  7. Salvage and storage of laboratory equipment and furniture
  8. Storage of models and samples

  Comment: In most laboratories there is not enough storage space

(g) Files and communication:
  1. Correspondence
  2. Documents
  3. Document preparation; mimeograph and other reproducing machinery
  4. Drawings
  5. Vault space required
  6. Telephone exchange
  7. Telegraph
  8. Teletype
  9. Messenger service

(h) Drafting rooms:
  1. Central or departmental

(i) Recreation:
  1. A cooperative store for employees' convenience
  2. Smoking and card rooms adjacent to cafeterias for mid-day use
  3. Soda fountain
  4. Cigarette, soft drink and candy dispenser stations at convenient centers
  5. Outdoors: horse shoes, soft ball, etc.

II. Laboratory Departments

General Comment: If departments are of sufficient size, should they occupy separate buildings?

(a) Three fundamental characteristics of occupancy have an effect upon the design of a research laboratory:
  1. The nature of the organization with respect to general management and division of work, i.e., whether the organization functions under a single control or under large or small autonomous groups.
  2. The work patterns within the laboratory regarding the normal pursuit of experiment from bench to semi-pilot and finally to pilot work. Here the division or lack of responsibility will have effects upon plan arrangement.
  3. The need for flexibility in prospective change and growth. It is quite obvious that all departments may not be equal in growth. It is rather difficult at times, therefore, to determine whether departmental groups with their variability in growth, should occupy a single building or separate ones. While the economy of the single building may seem obvious it is not the sole factor because when these are actually measured they may be readily outweighed by the desirability of providing the best housing for the work habits and temperamental comfort of different occupants.

(b) Office:
  1. Executive (private toilets)
  2. Group leaders
  3. Stenographic (individual or pool)
  4. Conference rooms

(c) Laboratory:
  1. General size (see p. 149)
  2. Personnel shops, i.e., small shops in which the scientific worker may do work for himself—generally under the supervision of a first-class machinist
  3. Glass washing
  4. Special requirement rooms, such as constant-temperature, balance rooms, semi-pilot, special hoods; microscopes, spectroscopy, photography and display, etc.
  5. Locker and change rooms for male and female personnel. Standards for determining the relationship of toilets, lavatories and showers to the number and work habits of the personnel. Rest rooms for women employees

(d) Special laboratory buildings and requirements:
  1. Pilot plants
  2. Development shops
  3. Experimental buildings for unusual work of dangerous nature
  4. Field experiments

(e) Medical department: size and number of employees. Medical staff, permanent or visiting?
  1. Employee examination } extent
  2. Employee medical care } extent
  3. First aid—central or departmental

(f) Library:
  1. Stack and file space (quantities necessary)
    A. Books
    B. Periodicals
    C. Technical papers
    D. Laboratory reports
    E. Patents
    F. Catalogue requirements
  2. Number of seats in central reading room

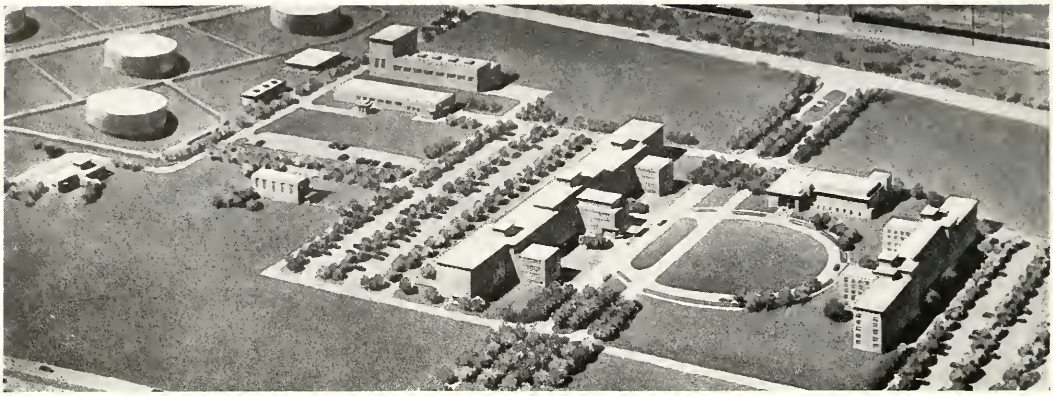


Figure III.2 Model study for the Research Laboratory Center, Standard Oil Development Company, Linden, New Jersey. Voorhees, Walker, Foley & Smith, Architects and Engineers.

  3. Departmental reading rooms (stack and reading space)
  4. Number of carrels
  5. Number of microfilm reading carrels
  6. Library personnel—offices and work space
  7. Translation and briefing requirements
- (g) Building maintenance:
  1. Locker rooms for watchmen, porters, janitors and mechanics
  2. Toilets
  3. Building maintenance shops—such as painting, carpentry, sheet metal, pipe, electrical, etc.
  4. Supply rooms
  5. Fire alarm and mechanical control rooms
  6. Watchmen's off-duty room

III. Outside Utilities

- (a) Water: volumes and pressures required
  1. Domestic use
  2. Process or industrial use which may require special waste disposal
  3. Air conditioning (cooling towers)
  4. Steam generation
  5. Type of fire protection
  6. Water for lawns and landscaping
- (b) Sewage and waste disposal: volumes required.
  1. Special treatment and industrial waste
  2. Domestic waste
  3. Incinerator
  4. Monitoring
- (c) Gas:
  1. Volume of domestic gas required and at what pressure
  2. Bottle gases. What special provision is deemed necessary—special center for storage—type of distribution
- (d) Electric light and power:
  1. Power requirements for laboratory use
  2. Type of lighting required (incandescent or fluorescent) (footcandles at bench height)
  3. Total current requirement—AC or DC?
  4. Will power be generated or purchased?
  5. Is voltage regulation necessary?
- (e) Steam:
  1. Requirements for heating
  2. Process steam
  3. Process hot water
  4. Type of fuel; storage facilities deemed necessary
- (f) Air conditioning:
  Industrial or comfort?
- (g) Transportation of supplies:
  1. Is a railroad siding desirable?
  2. Desirable distance by truck to normal supply centers

INFORMATION DESIRED TO DETERMINE SUITABILITY OF SITE UNDER SELECTION

For each site under consideration it is advisable to obtain the following documents and information:

- (a) Map showing relationship of the site to the neighboring city, with transportation—main highways and railroads
- (b) Map or survey of the property
- (c) Topographical survey of the site. (The national geodetic maps will give some indication if no other source is available)
- (d) Subsoil information, if available; if other

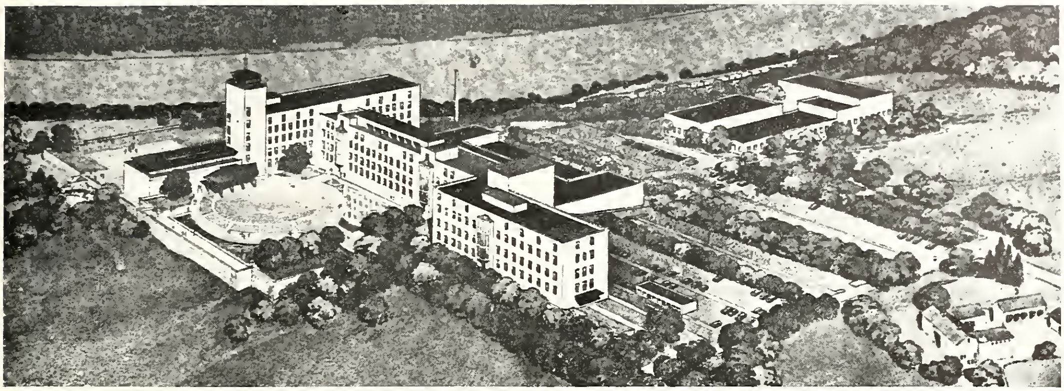


Figure III.3 Preliminary drawing of the Laboratory Center, General Electric Company at The Knolls, Schenectady, New York. Voorhees, Walker, Foley & Smith, Architects and Engineers.

industries have made borings or if well drillers have knowledge, these should be sought

(e) Zoning map and ordinance

(f) Building ordinance (local, if any. If not, state requirements should be ascertained)

(g) Aerial photographs

(h) Any master plan showing proposals of local, county or state planning agencies, especially with respect to roads and highways

(i) Rate schedules for
  1. Water
  2. Gas
  3. Electricity

(j) Maps and data of existing utilities showing sizes, sources and capacities

(k) Photographs of adjacent neighborhood

(l) State labor requirements

I. General Characteristics of Specific Sites

(a) Is the proposed site large enough for present needs, including adequate parking and proposed recreational facilities, plus future expansion of at least three times present thinking or in line with possibilities inherent in future research?

(b) Nature of surrounding land developments: rural, industrial or residential

(c) Can the existing character of the surrounding properties be maintained through zoning or will there be a sporadic growth of lunch wagons, saloons and other undesirable developments near the entrance of the property?

(d) A residential zone should not be excluded —which may be willingly re-zoned for an industrial use of no nuisance variety. In this case the areas immediately adjacent should be re-zoned also for limited and similar industrial purposes or a residential use which seems reasonable

(e) Is the site in more than one municipality? (It is obviously desirable to have the site in one taxing municipality)

(f) Are the highways leading to the site adequate to take the proposed traffic?

(g) Cost of land to be regarded in close relation with all the following sections

II. Topographical

(a) Is the site level or rolling? A site not exceeding 8% gradient is preferable

(b) What is the quality of the wooded growth —mature, second or weed growth? (If it is heavily wooded the clearing cost should be added to the acreage value)

(c) Is there adequate topsoil?

(d) Are there boulders or outcroppings of rock? If so it might be advisable to obtain the advice of a geologist, especially if the project is a large one

(e) What are subsoil conditions? Again, if the project is large it might be desirable to explore by pits and borings the most advantageous building sites

(f) What are the natural surface drainings, degree of erosion, swamps?

(g) Approximate water tables

III. Traffic and Locations

(a) How well developed are the surrounding streets? Character and gradients

(b) Are highways and community streets

properly maintained with particular reference to snow removal?

(c) How far to main highways?

(d) Will the preferable entrances to the property be satisfactory in relation to
  1. Contours of site?
  2. Dangerous highway intersections and curves in the bordering streets?

(e) Consult with the local and other authorities and obtain agreements as to necessary traffic improvement such as traffic circles, if deemed necessary

IV. Transportation

(a) Availability of railroad sidings
  1. It should be noted that an allowance for a minimum radius of 360 feet and a maximum gradient of 1½% should be made. For example, a 90° curve would require 3½ acres for the tangents to form a square

(b) Distance to passenger and freight stations—within distance range of local express company

(c) Distance to neighboring city

(d) Existing transit services to local railroad stations, employees' homes and shopping centers

(e) Can starting and finishing of work schedules be arranged so as not to interfere with school buses or other commuter traffic?

(f) Airport service, if any

AVAILABILITY OF UTILITIES

V. Water

(a) Is water for industrial use nearby? River, lake or existing wells

(b) What is the source of water for domestic use?

(c) Characteristics of water

(d) What are the sizes and ages of the mains in the adjacent streets?

(e) What is the water pressure, as designed? Actual?

VI. Fire Protection

(a) What is the availability of fire protection?

(b) What is the municipal fire protection, volunteer or professional?

(c) Where are the hydrants located?

VII. Local Sewage Disposal

(a) What are the sewage disposal facilities?

(b) How are the charges for use of the sewage facilities pro-rated?

(c) Type of treatment used in system

(d) Capacity available

(e) What treatment will the municipality require for industrial waste?

(f) Sizes of the existing adjacent sewers

(g) What spare capacity?

(h) Are existing storm sewers adequate or will the natural drainage take the new amount of proposed hard surfaces? Will holding ponds be necessary?

VIII. Refuse

(a) What are the facilities for wet and dry refuse disposal?

IX. Gas

(a) Are there gas mains in the adjacent streets?

(b) Manufactured or natural

(c) Capacity available

(d) Available pressures

X. Electric Light and Power

(a) Where are the power lines?

(b) What are the current characteristics?

(c) Capacity available and age of generating station and pole lines

(d) Network—possibilities of two sources

(e) Municipal or public utility

XI. Local Government

(a) Size of town

(b) Nature and quality of local government

(c) What is the tax rate?

(d) What relation does the present tax rate have on the building costs of any other industry in the town? Will the local government make any adjustment related to present costs?

(e) What is the ratio of assessed valuation to present market value?

(f) What are the prospects for the future growth of the community?

(g) What is the prospect for future tax increase or decrease? (Are roads, water supply, schools, in good condition?)

XII. Labor

(a) Type of labor

(b) Nationalities of labor

(c) Labor organizations—A.F.L. or C.I.O. or company

XIII. Other Industries

(a) What are the local industries?

(b) Are they well diversified?

(c) Facilities provided for the employees of these industries—kinds of recreation, housing, medical care, vacations, etc.

XIV. Housing

- (a) Where and what are the housing facilities in the neighboring communities?
- (b) What are the rent levels and the availability of houses at these rent levels? (Will the private builders easily meet the demand for new houses?)
- (c) What percentage of the people own their own houses?
- (d) Are the communities attractive?

XV. Schools

- (a) What are the school facilities in the neighboring communities—old or new? Adequate?
- (b) How are the schools situated in relation to residential sections of the community?
- (c) What is the average pay of the teachers in these schools?

General Comment

Sections XIV and XV are of vital importance to contented workers in any salary class. If the communities are attractive, if the schools are good—the teachers above average—the turnover of employment, all other things being equal, will be low.

XVI. Recreation

- (a) Theatres
- (b) Libraries
- (c) Playgrounds and parks
- (d) Type of citizen organizations: country clubs, town clubs, P.T.A.
- (e) Churches

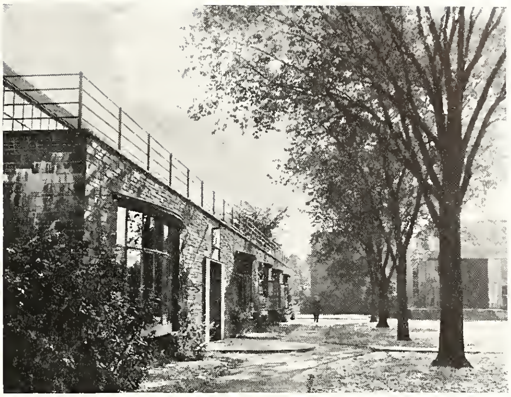


Figure III.4 Exterior of the cafeteria, Bell Telephone Laboratories, Murray Hill, New Jersey. Voorhees, Walker, Foley & Smith, Architects and Engineers.

XVII. General and Health

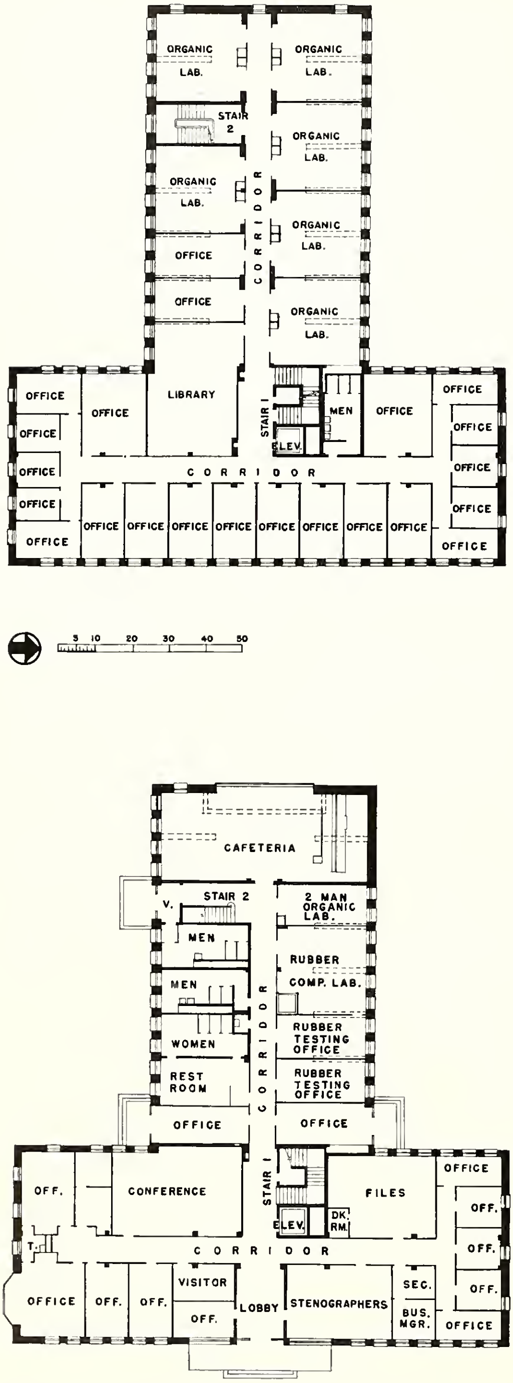
- (a) Character and extent of shopping facilities
- (b) Hospital facilities
- (c) Professional services—physicians, dentists, etc.
- (d) Those commercial facilities which are part of modern women's life—i.e., hairdressers, etc.

CONSIDERATION OF SITE DEVELOPMENT AND DESIGN

The whole theme of a laboratory development should be convenience tempered by those amenities which make work something other than a task. The laboratory establishment to be developed can finally either look like a monotonous factory or it can without too much extra expense give in part, at least, the qualities of simple, orderly arrangement related in scale to the quality of its occupants and to nature. If the site has been well selected with this in mind that result will depend more upon the intelligent use of nature than to the buildings erected. A good natural site can be easily ruined by the improper placing of buildings and by the careless performance of the builder. It must be remembered that the siting of any large building will disturb a surrounding extent of land at least equal to its own area and generally greater. This larger disturbance, of course, at times may be unavoidable, but a realization that it can be controlled if carefully planned will avoid later annoyances.

The whole site must be planned, not only as to the position of the buildings but also in the relation of the utilities to buildings and to themselves and especially to roads and future needs.

From the moment the builder approaches the project his activities should be coordinated; also, his office, the shacks of the subcontractors, their storage yards and sheds, the temporary parking of the workers, should be planned in such positions as to give the least interference to the nature of the site and to the final clearing up of the work. Dirt to be moved should be placed near where it is to be used eventually—topsoil piled neatly



Figures III.5 and 6 Floor plans. Esso Laboratories, Baton Rouge, Louisiana. Voorhees, Walker, Foley & Smith, Architects and Engineers.

and prepared for its possible increase while stacked. Rubbish piles should be removed promptly. A clean operation is apt to be an efficient one.

Primarily all site problems may be divided into present needs and their expansion zones. If this is done thoughtfully, a great deal of future opportunism may be avoided. Practically every building operation well accomplished goes into future expansion even though later the buildings themselves may be used for different purposes. These zones should be large enough for considerable growth and at the same time remain completely free of road underground services or those overhead, which are difficult to move, i.e., major power or steam lines. In planning the present buildings, diagrams of the several possibilities of future growth should be indicated and evaluated so as to determine the extent of these zones. While it is impossible to say that present day planning will never present obstacles and especially if further opportunism is followed, it still remains possible that a great deal of future trouble may be avoided.

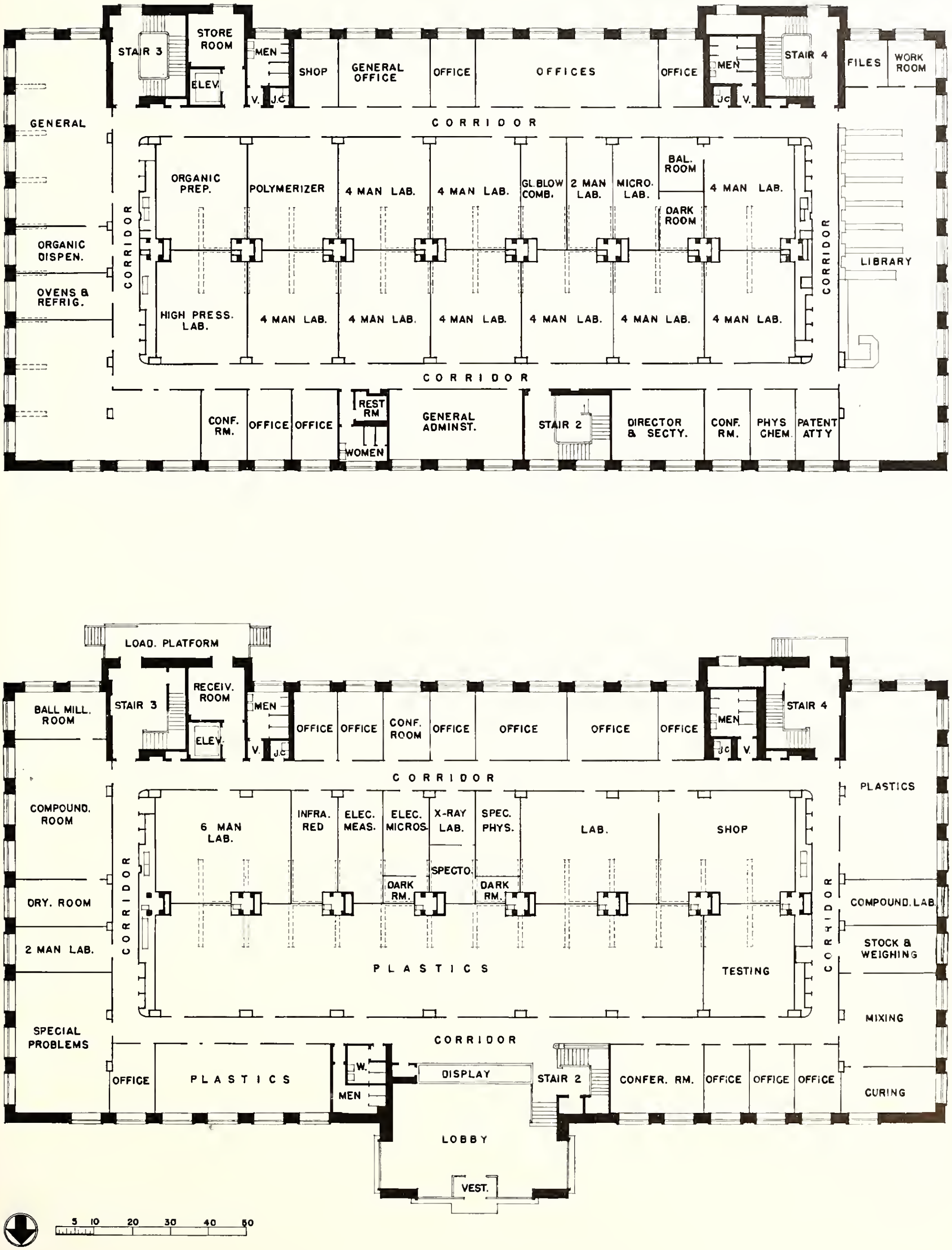
The main utilities should provide for a growth of 100% at least and their sources should be readily capable of even greater expansion, i.e., boiler plants and cooling towers especially: if the main runs are short a utility tunnel is of great value but where the runs are of great length its consideration must be determined by its relative cost to the entire project. Every step in utility design should be judged on the basis of engineering cost and the need for flexibility. No consideration whatsoever should ever be given to the unsupported phrase "it will cost more". Utilities should be designed to avoid roads wherever possible and to observe the best use of the land's contours. They should be thoroughly coordinated because an uncoordinated group of underground utilities can disturb an enormous land area. Each time a bulldozer is started its logical and continuous follow up of associated costs should be charted. There would seem no great economy in uselessly pushing earth around. The marginal lands have been indicated as generally producing greater building costs—so do, obviously, the lands with great outcroppings of rock—so probably do heavy floor loadings on filled land.

If buildings are large enough and widely separated, it is possible that cooling water might prove more economical if cooling towers were individual to buildings.

Every site should provide easy access from the main highways for auto and bus transportation and each type of need should be sorted out as to quantity and approach. Roads and approaches should be designed by competent planners in conjunction with local authorities and generally agreed upon before purchase.

Temporary advertising value along major highways can soon be lost entirely if the rest of the development along the way is devoted to customary helter-skelter ribbon use.

If an industry is welcome, it and the municipality may create agreements advantageous to both. Zoning ordinances may be changed for their mutual protection



Figures III.7 and 8 Floor plans. Firestone Research Laboratory, Akron, Ohio. Voorhees, Walker, Foley & Smith, Architects and Engineers.

and the surrounding area made desirable to both parties.

It is often desirable to control by purchase the opposite side of the main road from which the principal entrance is proposed.

Proper landscaping is worthwhile in consideration of amenity value; here the note of warning may be raised as to the operational expense. Planting should be considered for its permanency and broad all-over effects. As an example, trees can be chosen for their seasonal change. In the east the maples undergo four major color changes in the year. In spring, blossom; in summer and fall, the change in leaf color and finally as bare structure in the winter. If trees are planted with this in mind, the relative scale between large buildings and nature will be maintained.

A very important item to consider is proper orientation—sometimes the quality of the land will force the orientation. Laboratories facing north, if they do not have too large an area of window glass, might obviate the necessity of shades or venetian blinds and other similar dust catching devices and still escape glare. Orientation consideration should be given also to the neighboring causes of smoke and dust nuisance.

An avoidance of temporary construction is desirable because finally the only saving—a large amount—has been made in the character of the shelter itself—generally the cheapest part of the project, and it lives to constantly aggravate.

The general appearance of the laboratory building will be largely determined in the development of both laboratory and office modules—the size and repetition of the windows. Its public relations value can be created best by having it fit quietly into its neighborhood, advertising features such as useless and strident towers will in the long run deteriorate in public appreciation whereas the more nearly the result attains the simple generous character of a college campus the longer will be its term of esteem in the minds of both the worker and the public.

The site plan can readily develop a permanent front yard in which appearance is given the greatest consideration and then a generous part of the site can be set aside for buildings of temporary character, pilot plant and other field experiments in which the shelter is the important part. If this area is thought of as an orderly part of the plan the temporary quality of its buildings will harmonize with the larger scheme. Institutional in scale it should achieve that entity and character of its own which makes it readily recognizable as a desirable place to work.

2

INTERIOR ARRANGEMENT

Ralph T. Walker

Voorhees, Walker, Foley & Smith, New York, N. Y.

Having determined the general program and established it in principle upon a site, the character of the laboratory unit itself should be agreed upon, with its relationships to the offices of the laboratory workers, the group administrators, and of the major executive. It is desirable to have definite ideas as to where the mechanical and electrical facilities are to be located, their sources and the qualities and sizes of the runouts. It is not too early for the group leaders to instruct their co-workers to prepare on some agreed module the special requirements that each may have in mind. The early bringing together of this information may lead into a further understanding and modification of the dimensions of the module itself. It must be remembered that the design period and executive approval take considerable time. It will be found desirable to make a rough full-scale model or "mockup" of a standard laboratory to obtain further appreciation of the proposed solutions. This model when completed also has a value in instructing the sub-contracting pipe trades as to arrangements and clearances, before actual estimate proposals.

One may assume the need of accurate information brought together at the design stage to lessen later major additions to building and costs. Any laboratory building is a complex structure, costly at its most economical level, and therefore liable to have very excessive extras in costs if the specific details are not early understood and agreed to in both the owner's and the builder's mind.

It is not too lengthy a process to have the design carried into a thorough fundamental stage far beyond that generally considered as preliminary so that measured costs can be had. Even in times of inflation it is wise to have a fundamental budget based on other than approximate area or cube guesses. These fundamental plans and specifications should outline the general design principles of all major work to be accomplished, showing in line diagrams the requirements for the mechanical and electrical trades and for occupancy as well as for general architectural planning.

THE MODULE

The module is to be considered as a unit of work space determined by human needs. It is dimensional only through its use factors. In designing many laboratories the writer has yet to find anywhere that any single unit of work space is exactly similar to any other—the differences may be slight but obvious enough to create another problem and demand another solution. The character of the research carried on, the need for safety considerations in the width of aisles, for example, each determines the final result. In the development of a module's dimensions there is no general standard and each research group should indicate for itself the size and character of its working conditions.

The module may be, and usually is, different for laboratory and office work, and these differences can be readily composed in the final building without hardship to either. Fundamentally, these determinations aid in the achievement of orderly and disciplined arrangements.

The individual laboratory module of use has within it, generally, these facilities complete in themselves so that each module may become a complete room or the basis of a larger one. Each module should carry natural and artificial illumination; heat and ventilation with whatever air conditioning is needed and including hood exhausts; pipes for all major services and reserve space for future and special ones; required electric distribution; necessary sink and cup drainage; access from a common corridor where in need there will be found a safety shower; egress to another contiguous and occupied space for safety and, of course, the arrangement of floor area with table and aisle widths determined. When the desired characteristics of this module are agreed upon—its dimensions, its required facilities—then a repetitive mechanical system can be designed to service the entire laboratory; for the chief advantage of the module system is the known repetitive position of services and therefore the lack of interference between one laboratory at work and another in preparation for a new project requiring special and additional services. The individual laboratory module is but a unit of a complete source of facilities. It is obvious that it is in effect most economical where the space developed is on two to four modules; for while it is generally accepted that a module may be of sufficient space for one table worker and an assistant; the characteristic laboratory developed is usually two modules in width. Any space beyond four modules in width brings into consideration so many possible arrangements of use that the main advantage which remains is in the known position of services offered.

The length of the module from corridor to exterior wall is apt to be determined by whether or not the table worker also has a desk within his module. The addition of a desk, a visitor's chair and a file cabinet of course lengthens the work area.

Another factor in length is the method of safety escape used. There is almost complete agreement that in case of an accident—a fire or a chemical spill—the one affected generally needs the immediate help of someone else, or if he is alone he must be able to move with the least difficulty toward attention, help and safety areas.

The best answer, even though it requires more space, is a well-placed door communicating with an adjacent room—preferably between the worker's desk and the last table unit. This door can be smaller than the one giving access to the corridor. Another device is an escape panel placed over the desk with the sill approximately 4 feet from the floor; this panel released by a simple push device. This does not seem a satisfactory escape device especially for someone seriously injured, confused or alarmed because of other dangerous possibilities. It has been the writer's observation that, when used, *the safety committee* has a continuous job of seeing that additional hazardous things are not put in the way of escape.

The present-day engineering mind asks whether, in days of air conditioning (more often required for process work than human comfort) and fluorescent lighting, the window is absolutely necessary. *Illuminating Engineering* says it is a poor lighting device needing shades of one sort or another when the sky is bright to avoid annoying glare, and when the days are dull artificial illumination must be used anyway; in fact, good engineering claims, with reason, that regardless of whether the window is large or small, artificial light is necessary to remove the gloom from the interiors of most rooms deeper than 15 feet or more from the windows. The window is, without doubt in these days, a wholly psychological device permitting the mind to relax.

However, given the premise that windows could be made reasonably tight and so avoid the infiltration of dust, the writer, after interviewing men through many industrial laboratories, has yet to meet any worker who did not desire to have the window. He might be content with, even desire the windowless space for some tasks, but he fundamentally resents the involuntary sense of enclosure and especially if he believes it unnecessary. The movement of research laboratories into rural surroundings is predicated on the premise of a much more normal and traditional working life—part of which is the ability of viewing a pleasant outer world.

We might assume then that the module or unit work space is one concerned with convenience, safety, and amenity devoted to the activities of the curious.

Laboratory modules have varied in width as follows: 6'0", 10'6", 11'0", 12'0", to as high as one double laboratory, i.e., 24'0". Office modules vary as follows, based on a desirable width of office, i.e., 4'6", 5'0", 5'6", 8'0".

Finally, here are words of caution: there are obvious safety notes in the planning use of the module to avoid possible traps such as:

1. A "cul-de-sac" arrangement of tables.
2. The placing of hoods at narrow points of access.
3. *The use of safety doors to unoccupied spaces, service corridors, etc.*

And to the scientist, who will always need flexibility, remember, *never accept* the unproved statement—"It will cost more." Ask for a real estimate.

RELATIONSHIP OF TABLE TO DESK WORK

Research is not arrived at solely by experiment on tables in laboratories. There is, of course, a great deal of surveying necessary to initial research. The writer's firm has found that approximately 40% to 50% of a research man's time is devoted to surveys or report making. It is essential that he be given a desk and finally secretarial help. Further, it is our experience that most large, organized research groups require from 25% to 35% of office-type space other than desks in laboratories. This requirement may include special laboratories which do not require complete mechanical services. It does not include libraries and major executive offices which vary, of course, according to specific requirements. It might be said, however, that all technical libraries, after their initial growth, are recognized as doubling in size in approximately eleven years. Therefore, they should be placed so as to permit expansion.

There are several ways in which office space is planned in relation to the table laboratories:

A. In universal space, i.e., space developed and serviced for laboratory use.

B. Immediately across the corridor from especially designed laboratory space.
C. Office wings off the main laboratory corridor either at core points or at building ends.

A. Offices in Universal Space

This plan at first looks extremely economical in that it seemingly provides for a future growth in laboratory use. However, if most of the offices are arranged as suggested in C, above, the universal space in the main body of the building space may be more economical; but if offices are placed within laboratories, the supposed economy can be definitely measured. It was estimated in 1948 that laboratory floor area, with all its attendant mains and risers but no runouts, adds approximately $4.00 per square foot over a straight office space placed in wings (less a difference, of course, if office space is directly opposite). This extra cost is given as an approximation because it is obvious that the extent of services required will change the accuracy of the estimate. The fact remains, however, that in all cases known to the writer, the need for office space per se remains and, further, has not shown any tendency to diminish. This consideration may not apply to a process laboratory doing purely analytical work for manufacturing ends.

On the other hand, another study has shown that to deepen a laboratory unit by x number of feet without increasing the services themselves, the additional cost per square foot will be approximately in ratio of $15.00 for full services to $5.00 for the increased but unserviced area. Again the same note of caution applies to such an approximation, which, if and when authenticated for each new project, may be used in relation to desk space and safety doors to adjacent rooms.

B. The Office Immediately Across the Corridor from the Laboratory

This type of space has many advantages. It can be used for office space or it can be used for those laboratory purposes which need very few services. It can also be readily reached in time of urgent need with services arranged in a temporary manner to give additional table use. Of course, the same disadvantage exists as in universal space in that finally the office requirements must be adequately provided for and while the immediate economies are evident, the economics would seem to lead to other conclusions.

C. Office Wings off the Main Laboratory Corridor Either at Stair and Elevator Cores or at the Ends of Buildings

This scheme would seem to be a step in a reasoned solution; for if all laboratory space were developed about a common corridor as indicated in A. there would still exist a need for definite office space; this office space may well be placed in wings to form T arrangements with the laboratory space and at the necessary stair and elevator cores. These core centers should not be placed much more than 175 feet apart. It is safe building practice to put the stairways at the ends of laboratory corridors. The writer, however, has come to believe that the best relationship between laboratory and office space is a combination of B and C. This seems to offer the greatest amount of flexibility in use without any loss in economy; and creates the opportunity for the group leaders to be close to co-workers; and offers also the opportunity of placing special requirement rooms in close adjacency to laboratories, thereby giving to the associated desk worker in the office wings a close proximity to the men in the laboratory.

GENERAL LABORATORY ARRANGEMENT, TYPE OF PARTITION & DISTRIBUTION OF SERVICES

These three factors are so immediately tied together that they must be discussed at the same time. Depending upon which relationship of laboratory and office space is used, the general laboratory arrangement is further affected as indicated by three factors—the use of the window, the need of desk space, and the placing of the safety exit. Mechanical and electrical services can be brought to laboratory tables in multistory buildings in several ways:

1. From the outside wall at the piers between windows. This, of course, precludes a safety door near the outside wall because of the pipe runouts and therefore leads to the use of an escape hatch or panel above the desks or tables. The services on the exterior wall are generally covered by a metal detachable wainscoting and are distributed vertically from basement or attic mains, and horizontally beneath the window sills for runouts to island tables. The latter may be attached directly to form a peninsula or through trenches to form a true island.
2. From the corridor where vertical shafts are formed in the structure and covered with metal wainscoting and from which at the modules runout piping feeds the tables. Here, of course, is an opportunity for an escape door at the exterior wall and also a freer use of that wall for office desk space. These interior chases form a thick wall leading to the corridor, and where not needed for facilities can be used as cupboards—both in and out of the laboratory—for clothes, glassware, tank gases, etc. An added advantage is the possibility of having doors leading from laboratories to corridors which, when open, do not extend into the corridor itself. Further it permits all work on the mechanical and electrical facilities, repair or new, to proceed with the least interruption to the occupants of nearby laboratories.

3. By a series of shafts on the interior of the building which feed four laboratory modules from a common center. All the laboratories are back to back and the runouts lead out like a cross from this common center, again forcing, of course, the use of the escape hatch or panel. This plan results, moreover, in a group of interior laboratories, and it is questionable whether in a multistory building it leads to the assumed economies. The shafts must be generous enough to permit workmen to work freely within them. When the hazard factors are summed up, the next step is to try to develop an interior service corridor to gain more flexibility and thus to eliminate the confused and complicated crossings of pipes, ducts, etc. Safety doors leading to this corridor are, probably, the worst of all in design in that generally this type of corridor encourages in practice banks of pipes in wrong places and, moreover, is *unoccupied*.
4. The very oldest way, i.e., exposed piping hung on the ceilings and extended either up through the floor to service the tables above or downward to the tables below. Both have their nuisance factors, and moreover, in a multi-story building they are not as economical in pipe layout as they would seem. One main service distribution system can be increased in capacity without materially increased size of pipes, so that vertical runs away from such main lines are not much longer than the horizontals in the old method; a module of 11 to 12 feet being equal to a story height. The horizontal runs at the tables will remain much the same and are much smaller pipe sizes. A study made in 1947, a comparison between a horizontal main distribution of single service at each floor and a main service in either attic or basement of a multi-story building showed a material saving in favor of the single horizontal bank of mains with the vertical runs. Here material and labor savings made the seemingly obvious not the most economical.

There is a further refinement in the main horizontal run which is applicable to a two-story building, and that is to build a service gallery between the first and second floors and to place all the services there and then feed up and down. The writer believes this method is not desirable; and in comparison, and especially where ground water conditions make it impossible to have a basement, an attic above the second floor would seem a better device, one developing more usable and better work space at about the same cost, the vertical distribution being much the same.

There is much to be said for the economy for both a service basement and an attic. They work fairly well for three or more story laboratory buildings. There is always a great amount of building equipment, and with the continued and growing use of air conditioning of all kinds there is an increasing need for adequate machine space. There is a false economy in making spaces holding machinery so small that it is difficult to see the apparent need of repairs, which therefore are put off until a major operation becomes necessary. Both basement and attic can be used for a great deal of secondary laboratory purposes and especially for one of which there never seems enough, i.e., storage. Care, however, should be taken to place machinery such as compressors in those parts of the building where they will cause the least acoustic disturbance. There is a growing knowledge respecting the correction of these disturbances which enables a wide choice of space—so expert advice on acoustics is desirable.

There has been no attempt to enter into detailed consideration of any of the service problems. Here the general discussion has been to indicate the several ways in which the distribution may be accomplished, but again the writer believes that the answer must fit the special conditions. It is obvious, that with the use of radioactive materials, for example, a wholly new group of considerations must be undertaken and unusual solutions attained. The comparative cost of the several ideas will be influential in the final determination of the one used.

PARTITIONS

The need for the greatest flexibility and an unknown future—most research men agreeing that no one can foretell the frontiers ten years from now—have led to a wide use of movable partitions. These partitions are factory made units, approximately 4 feet wide, which two men can readily handle—with interchangeable sections giving freedom in placing doors—and with an infinite possibility of shelf and service arrangement on the wall surfaces, through the means of keyhole fitting attachments; and these devices have become recognized as very desirable whether or not the entire partition is ever moved. If the partitions are metal, the finish —a "baked on" enamel—has a long life of good appearance for the paint is of a kind from which the average laboratory spill is readily washed without disastrous stain or damage.

The partitions separating one laboratory from another can be designed also in many other ways: constructed of stock building blocks of terra cotta, cement or gypsum covered with plaster or painted. Services on this type of partition may be placed on racks supported from "Unistruts," a supporting device which is bolted into the wall on definite centers. (The placing of pipe services within the table is obviously not economical.) "Unistruts" can be run either horizontally or vertically. If, however, it is desired to support heavy structures on the wall surface, it may be necessary with this form of construction to bolt the support firmly through the wall.

Another type of wall construction is that using architectural tile blocks integral in the wall, either as smooth face terra cotta or with a ceramic finish. It has been the experience of the writer that when the means of fastening services has been applied to this type of structure, the resulting costs are not far different from the movable metal partition. There is no question that if flexibility is not considered necessary, this type of wall and surface is entirely satisfactory. It must be remembered, however, that the tearing down of such a wall will cause a large measure of annoyance through noise, dust and quantity of debris.

Other movable partitions are made of such materials as asbestos board and "Masonite". Both give desirable surfaces; but while they both may carry hard paint, they are difficult of salvage.

In all cases where movable partitions are to be used the building must be designed for them. It must be thought of as being made up of standardized units both in lateral and vertical dimensions. There is, otherwise, no economy in their use. One of the great mistakes in thinking, we have found, is the assumption that this type of building can be designed on any other basis than on a coordinated modular system; the more standardized its parts, the more economically it functions.

RUNOUT SERVICES

It was indicated that services should not be attached to tables. This again is a matter of flexibility in adding services as the tables can be withdrawn from their contact with the wall and replaced by a rack or by a new arrangement of tables, hoods or other equipment.

The services then are supported upon surface wall brackets. The outlets, cocks and cup drains are brought to the table level by means of a service strip on which they are conveniently spotted for use. Island and peninsula tables have a pipe rack support between them on which can be arranged services and drains, which in the former are carried from the main vertical pipe lines to the island support in underfloor ducts. To allow for these and future ducts on modular points it is necessary to provide a light-weight floor fill, one easily removed, of at least 5 inches in depth. In the underfloor duct and in the vertical shafts care must be taken to allow adequate working space between the pipes themselves. Electrical services are generally brought in from breakers or panels in protected ducts supported above the mechanical service strip below. The characteristics of this strip are, of course, determined by the general and special needs of the laboratory.

The matter of construction costs is worthy of consideration because all through the project questions of values and economies will be raised. The writer has lately found it advantageous, and so have his clients, to break the project down into four principal categories: Utilities, building site development, building construction, and occupancy.

It is obvious that it is difficult to compare one laboratory project with another unless the costs of these four factors are known. The following definitions are illustrative.

Utilities

These will comprise the main distribution of the service as well as its source equipment and structures. *It will not include branch runs into buildings.* The utilities are as follows: steam, domestic water, laboratory service water, sanitary and storm sewers, laboratory waste, railroad, illuminating gas, condenser water, roads, general area lighting, fencing, electric power, communications, fire alarm, and general landscaping.

Building Site Development

This includes rough and finished grading, driveways, walks, surface drainage and utility services from main stems by branches to within 5 feet of the building or meter; necessary outdoor lighting, parking of cars if adjacent to building, fence if individual to building: all of which presupposes, of course, that a predetermined lot or zone in the site has been assigned to the building.

Building Construction

This embraces all work (except occupancy) from 5 feet outside the building line, all lateral mains and vertical risers in a multi-story building (but no runouts) for all services, permanent and movable partitions, general illumination, heating, cores with elevators, toilets, stairs, etc., comfort air conditioning, bridge cranes, monorails and chain hoists, and manifolds for centrally distributed special gases. It is questionable whether a building for so special a purpose can ever be considered as a pure "loft" building.

Occupancy

In general, occupancy includes electrical and mechanical branches within the individual laboratory areas, with connections to service strips and equipment, plus all the equipment and the installation of special equipment furnished by the owner. Equipment includes fume hoods, laboratory work benches and tables, stools, furniture in record rooms, filing cabinets, steel shelving, library stacks, furniture in offices and lobbies, venetian blinds, curtains, draperies, tables and chairs in cafeteria, kitchen equipment, cabinets, fire extinguishers, electric fans, auditorium sound system, electric equipment for special services, synchronous electric clocks, microfilm unit and viewers, reproduction equipment, theatre seats for auditorium, and special process air conditioning. (Note: the electrical service under this definition would be building construction up to and including panel boards with breakers; laboratory power branch runs, switches, and breakers beyond this point should be classed as occupancy. In the case of lighting the conduit and switches installed in permanent partitions would be classed as building construction, whereas switch legs and convenience outlets in the movable partitions would be occupancy.)

3

ANALYTICAL CONTROL LABORATORIES

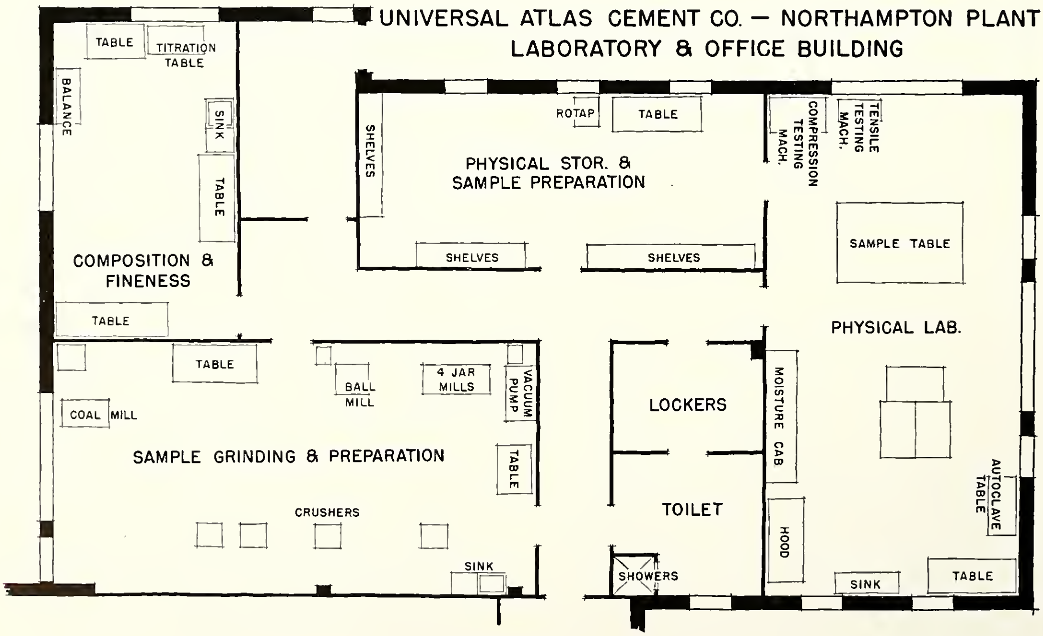
SECTION 1: Examples of Laboratories

Committee of the Scientific Apparatus Makers Association

American industry has come to consider production control laboratories as necessary as cost accountants and industrial engineers. Some such laboratories are merely a work bench located handy to a vat so that frequent titrations can be made, while others are larger and centrally located where samples can be sent by pneumatic tube or messenger from all parts of the plant and results reported by telephone, public address system or Telautograph. The particular design, location and equipment employed are all closely keyed to the particular control problems of the plant, the product being controlled, and the analytical methods used.

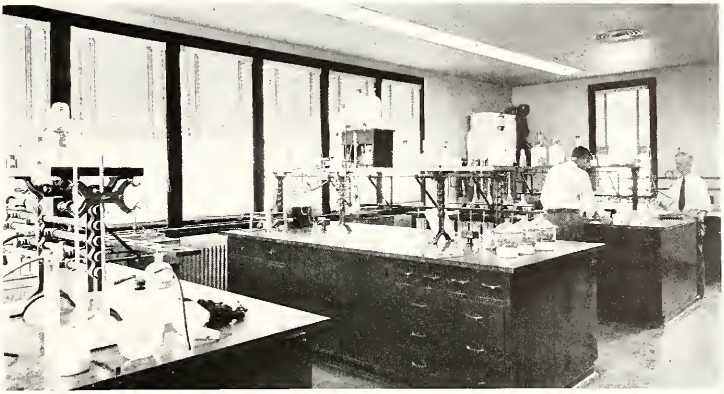
Thus, it is next to impossible to make any general statements governing the design and construction of industrial control laboratories other than to say that it is most important to locate them centrally and design them to give the same efficient service expected of other service departments within the plant.

In preparing this chapter, the committee felt it advisable to illustrate and describe typical examples of control laboratories which are well designed and equipped to service certain basic industries. The industries chosen are merely typical of many others and are intended to show how the designers located, con-


UNIVERSAL ATLAS CEMENT CO. — NORTHAMPTON PLANT
LABORATORY & OFFICE BUILDING

BASEMENT

Figures III.9a and b, Cement Laboratories. Universal Atlas Cement Company, Northampton, Pennsylvania. Below, basement and first floor plans.



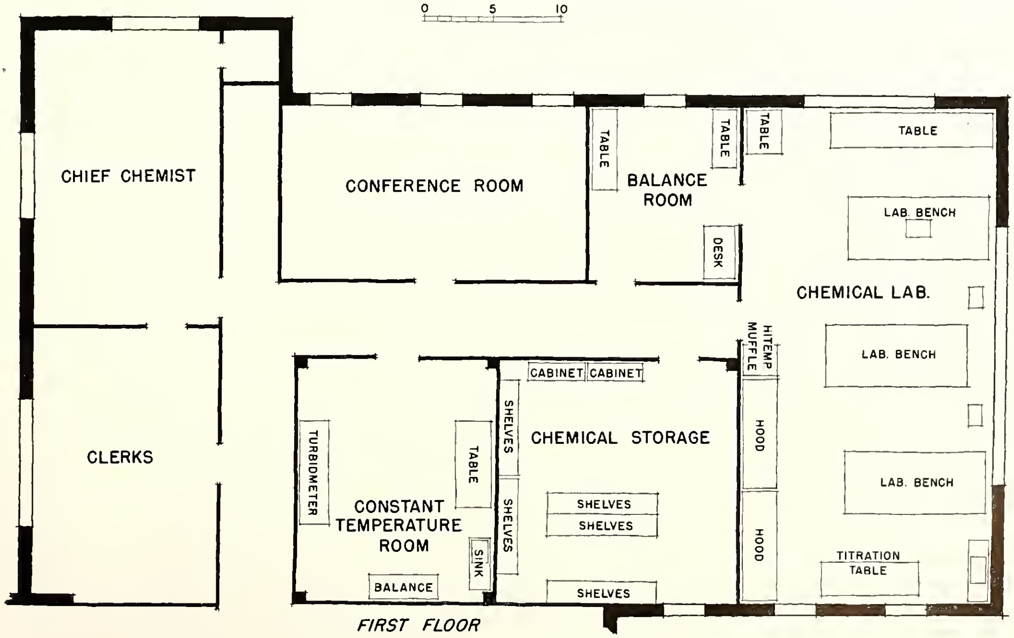
structed and equipped these laboratories to perform very specific analyses in large numbers (often on a 24-hour per day basis) with speed and accuracy. These designs are as truly functional as are found anywhere today. All the examples show care in the design of lighting and ventilating systems, while the floor plan and equipment location have been arranged for the particular methods of analyses employed.

It is hoped that by showing a floor plan, an interior view and giving a brief statement covering the functions, problems, methods and personnel of each lab, the reader will be able to find quickly the features of greatest interest to him.

CEMENT LABORATORIES

The laboratory of the Universal Atlas Cement Company, Northampton, Pennsylvania (figures III.9a and III.9b) occupies about 5,400 square feet in the basement and first floor of a laboratory and office building. Samples are stored, prepared and physical tests are run in the basement. The laboratory not only controls the quality of the cement made in the plant (about 6 samples per day) but also analyzes gypsum, coal and boiler water totaling about 75 determinations per day.

The following physical tests of cement are made: setting time, specific surface (raw material and fin-



ished product), tensile strength, compression strength, expansion and contraction, particle size. Chemical tests of cement include: SiO_2, Fe_2O_3, MgO, Al_2O_3, CaO, SO_3, alkalies, insoluble matter. Total ash, volatile matter, carbon, sulfur, moisture and BTU determinations are made on coal while boiler water is analyzed for phosphates and total solids.

The laboratory employs eighteen people of whom three are technically trained and four are technicians.

The floors of the laboratory are concrete with asphalt tile or linoleum. The walls and ceilings are plaster. The laboratory is winter and summer air-conditioned and fluorescent lighted. The furniture is steel with natural stone tops.

Among the major items of equipment are the following: 2 rotary crushers, gyratory crushers, jaw crushers, coal cracker, 8 ball mills, steel tube mill, drying oven, constant-temperature and humidity closet, sieve shaker, compression test machine, tensile test machine, small cement mixer, water-retention apparatus, workability apparatus, flow table, Vicat and Gilmore setting-time apparatus, 6 analytical balances, 2 autoclaves, 3 muffle furnaces, air-permeability apparatus, reflectance meter, 3 fume hoods, 2 microscopes, hydraulic press, glass-electrode pH meter, 4 hot plates, 2 viscosimeters, flash and fire point tester, Orsat gas analysis apparatus, ultimate-analysis train, electrolytic analyzer, water still (1½ gallons/hour), colorimeter, turbidimeter, conductivity bridge.

CONSUMER INDUSTRY LABORATORIES

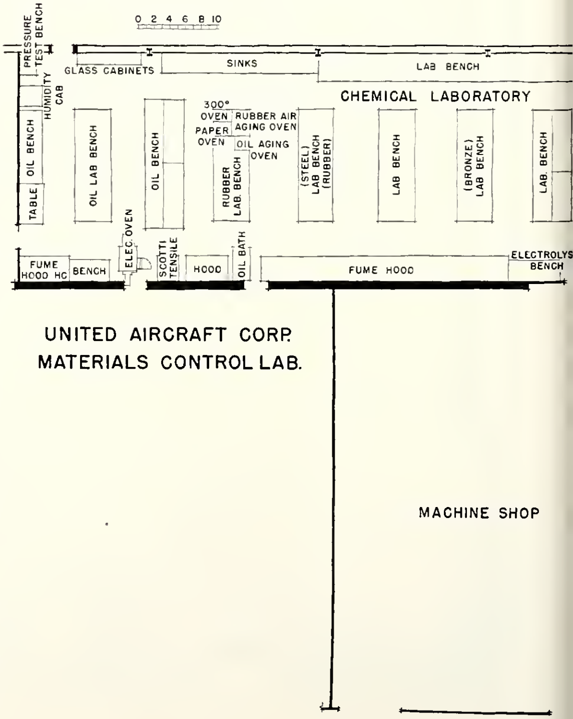
This laboratory of the Pratt & Whitney Division of the United Aircraft Corporation, East Hartford, Connecticut (figures III.10a and III.10b) is an outstanding example of a large consumer industry's control laboratory designed to test the quality of a large number of widely different purchased products. The laboratory is used to analyze and test such materials as steels, aluminum, brass, bronze, lubricating and cutting oils, plastics, rubber, papers, paints, wood and petroleum products, all of which are used in connection with the manufacture and test of aircraft engines. The laboratory, including its own machine shop, occupies about 11,000 square feet.

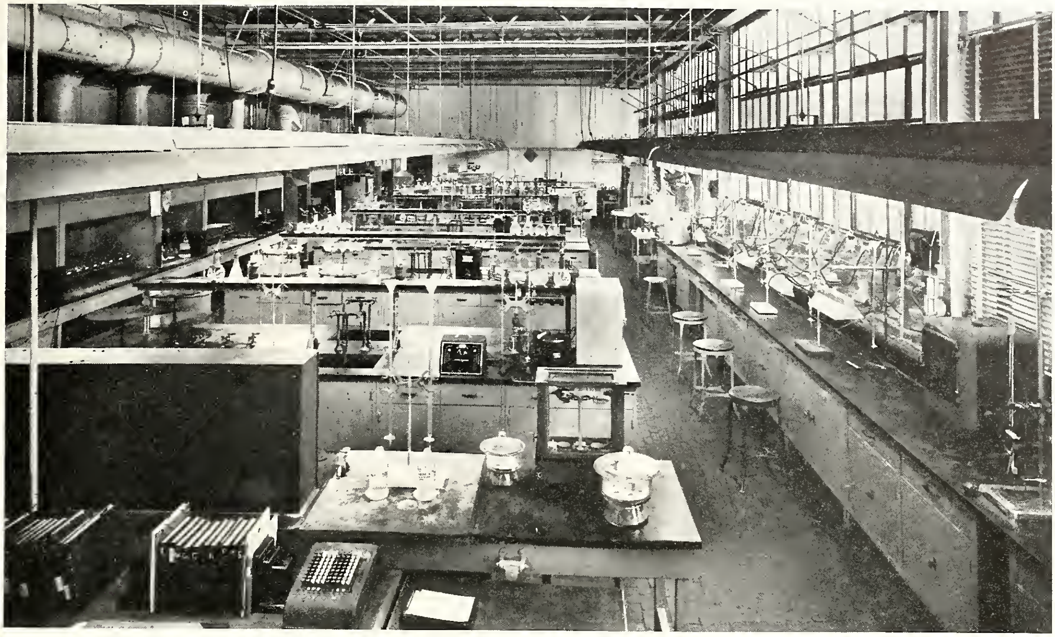
The following physical tests on metals are performed: tensile strength, yield point, elongation, hardness, bending strength, flare, microstructure examination, hardenability, case hardness depth, x-ray radiographs. Chemical or spectrographic determinations are made for the following elements: C, Mg, Mn, Ni, Cr, Mo, Va, Co, Ti, Si, N, Al, Cu, Mn, Sn, Pb, As, Zn, Cb. The laboratory analyzes about 150 samples per day making about 325 determinations.

The laboratory staff consists of 140 persons of whom 65 are technically trained and 23 are technicians.

Floors in the heat-treating room, machine shop and chemical room (except in front of hoods) are wood block. Floors in the x-ray room and spectrographic room are linoleum. Acoustic ceilings are used in the offices while the laboratory ceilings are cement. Walls are combination steel, wood and hard-board. Fluorescent lighting is used throughout. Air in the spectrographic room is conditioned; other rooms are forced-draft ventilated. Laboratory furniture is steel with stone tops.

Among the major items of laboratory equipment are: 7 fume hoods (6 designed especially for perchloric acid use), 13 chain-type analytical balances, 6 drying ovens, 4 viscometers, 1 polarograph, 6 creep testers, 5 muffle furnaces, 2 x-ray machines, 6 hardness testers, 3 tensile testers, 1 metallograph, 3 table microscopes, specimen grinder, 6 specimen polishers, 3 specimen-mounting presses, 14 electrolysis apparatus units, Orsat gas analyzer, 4 heat-treating units, optical pyrometer, 3 electrometric titration apparatus, grating spectrograph, prism spectrograph, 2 salt-spray test chambers, 2 humidity cabinets, 2 centrifuges, rubber-aging oven, hardenability tester, sieve shaker, paper tester and magnetic-flow test apparatus.





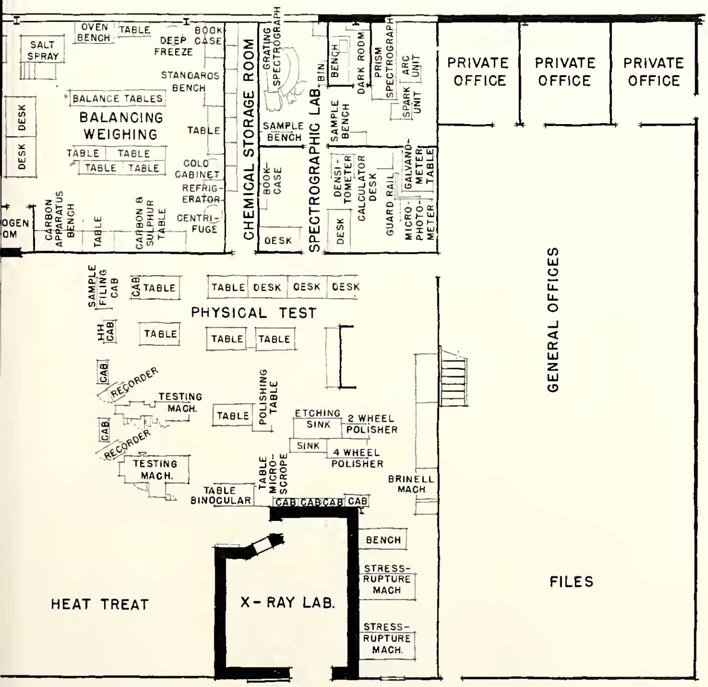


Figure III.10a, above, Consumer Industry Laboratories. Pratt & Whitney Division, United Aircraft Corp., Hartford, Connecticut. Figure III.10b, left, plan of the same laboratory.

Figures III.11a and b, Distillery Laboratories. Joseph E. Seagram & Sons, Inc., Louisville, Kentucky. Below, floor plan of the same laboratory.

DISTILLERY LABORATORIES

This laboratory of Joseph E. Seagram & Sons, Inc., Louisville, Kentucky (figures III.11a and III.11b) is an excellent example of layout and construction specifically worked out for the quality control of whiskey, gin, neutral spirits and the dried grains and dry solubles employed in the manufacture of whiskey. Some work is also done in analyzing coal and testing bottles.

Principal determinations made by the staff of 23 persons are: refractive index, pH, esters, acids, aldehydes, fusel oil, ash, protein, moisture, crude fiber, fats and riboflavin. About 100 samples per day (24 hour operation of laboratory) require about 500 individual determinations per day. Five of the personnel are samplers who take samples, transfer them to the laboratory and mark and package them in glass.

The floor of the laboratory is covered with rubber tile while the ceiling is acoustical tile surrounding the unusual square fluorescent lighting fixtures which are flush with the ceiling. Large tile squares form the interior partitions. The ventilation is forced draft. The steel laboratory tables have resin impregnated stone tops. The built-in stainless steel incubators, ovens and sterilizer are worthy of special note.

Some of the larger pieces of equipment employed include: 5 ovens, 2 refractometers, 2 water baths, electrical moisture meter, muffle furnaces, 2 pH meters, bomb calorimeter, automatic moisture oven, 2 analytical balances, Kjeldahl units, coal grinder, sieve shaker, 2 viscosimeters and 2 autoclaves.

Figure III.11b

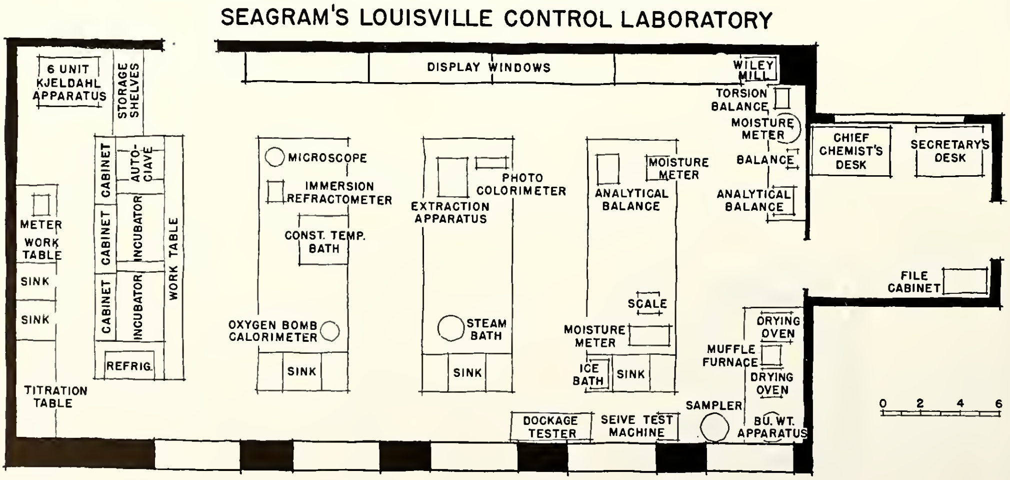
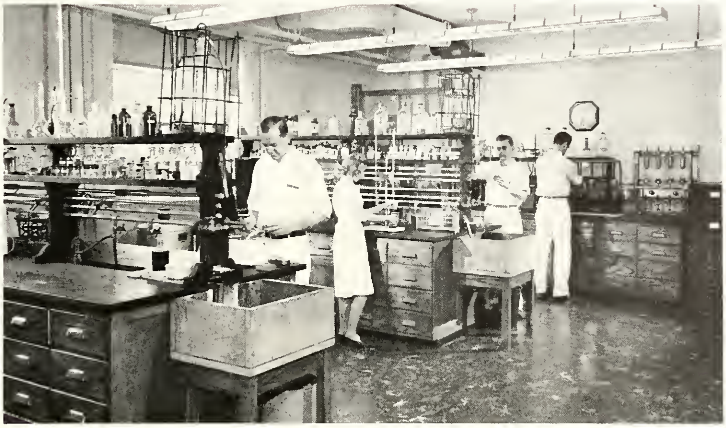


Figure III.12a, Food Laboratories. General Mills, Inc., Minneapolis, Minnesota.



FOOD LABORATORIES

The laboratories of General Mills, Inc., Minneapolis, Minnesota (figures III.12a and III.12b) occupy about 5,000 square feet and represent examples of careful planning to meet the problems involved in the control of quality of flour and cereal food products. Among the physical tests performed are baking tests, wheat surveys and physical control of flour for domestic and commercial use. Chemical tests include such determinations as fat, fibre, protein, ash, acidity, color, viscosity, vitamins and the development of new test methods. In addition to these product controls, the laboratories are called upon to check all packaging materials (paper, etc.), inspect packaged grocery products and perform nutritional studies.

About 175 samples are tested each day and require about 550 individual determinations. The staff numbers 35, of whom 20 are technically trained and 8 are technicians.

The entire laboratory space has asphalt tile flooring and concrete ceilings; walls are plaster. All lighting is fluorescent and ventilation is by forced draft. The windows are glass block and furniture is wood with stone tops and sinks.

Among the major items of equipment are: 5 analytical balances, 5 baking ovens, 18 Kjeldahl units, pH meter, electrometric titration apparatus, paper strength tester, stiffness tester, refractometer, 2 photoelectric photometers, 2 microscopes, densometer, 2 muffle furnaces, constant-temperature cabinet, autoclave, 3 moisture ovens, mixograph, farinograph, vacuum oven, viscosimeter, conditioning cabinet and spectrophotometer.

The laboratories of the H. J. Heinz Company, Pittsburgh, Pennsylvania (figures III.13a and III.13b) occupy about 5,800 square feet on the fourth floor of a large building centrally located among other food processing buildings. They are called upon to control all phases of food quality including bacteriological determinations, sugar, salt, acid, solids, protein, fat, trace metals and spray residue determinations.

A staff of 17, of whom 9 are technically trained and 5 are technicians, man the laboratories. About 110 samples are tested per day requiring a total of about 175 individual determinations. Samples are brought to the laboratory via mail from field stations and by special messenger from the plant. Refrigerated storage space for samples is provided.

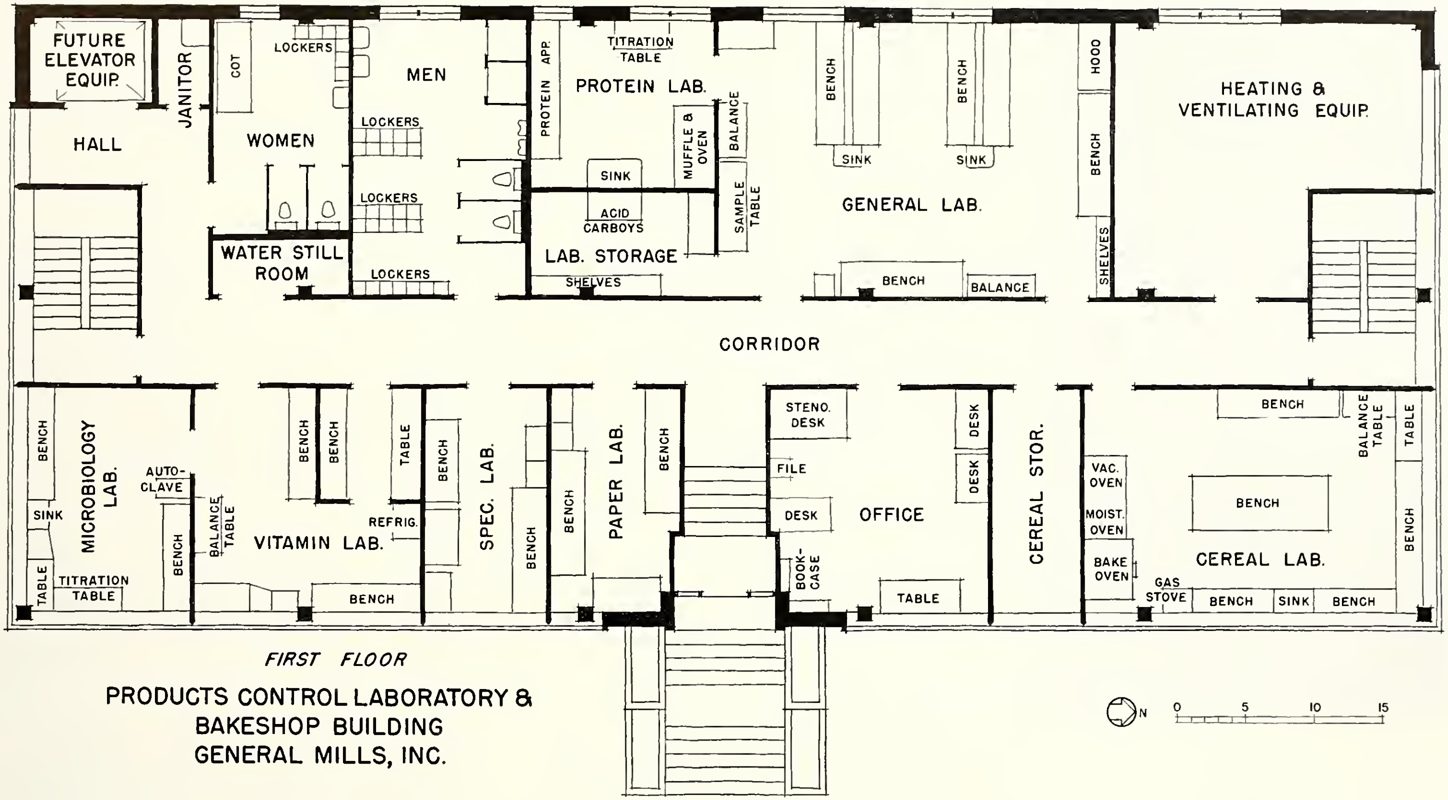
The floors of the laboratories are wood; ceilings and walls are plaster; all lighting is fluorescent; furniture is steel with stone tops.

Among the major items of apparatus employed are the following: 2 vacuum ovens, steam bath, 2 muffle furnaces, polarograph, refractometers, 2 pH meters, saccharimeter, colorimeter, constant-temperature bath, 9 analytical balances, viscosimeter, mechanical stirrers, sieve shaker, 2 alcohol stills, Kjeldahl apparatus, moisture tester for grain, cream test centrifuge, infrared heater, cutting mill and constant-temperature cabinet.

GLASS LABORATORIES

The Corning Glass Works, Corning, New York, has three control laboratories at this plant (figures III.14a and III.14b), one controlling raw material quality, another controlling physical properties of the glass during melting and the third controlling the finished products. Our description is confined to the last mentioned—the Quality Control of Finished Products Laboratory which occupies about 2,100 square feet.

The laboratory for thermal shock resistance tests such finished products as baking ware, chemical beakers and flasks and nursing bottles. Pieces of glassware such as television tubes built to withstand high external pressures are given hydrostatic pressure tests. Where internal pressure resistance is important, the glass parts are tested with water under pressure in a protective enclosure. Stress measurements are also



FIRST FLOOR

PRODUCTS CONTROL LABORATORY &
BAKESHOP BUILDING
GENERAL MILLS, INC.

Figure 111.12b

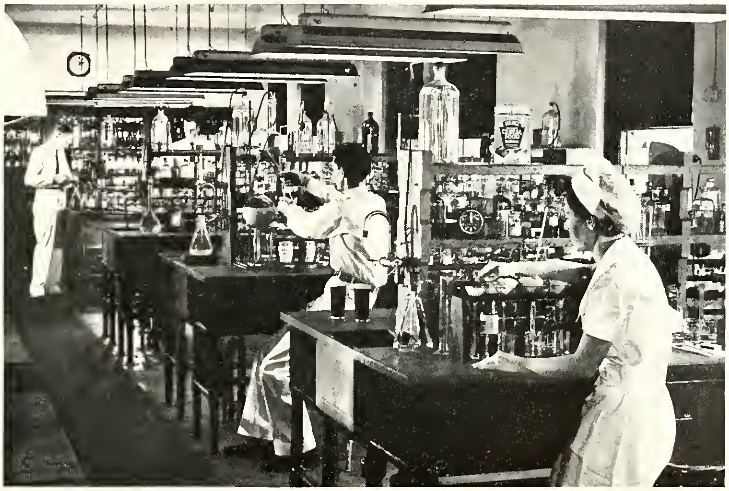
made to check on both annealing and tempering (heat strengthening) operations. Inspection is given glassware for air bubbles, striations and other defects. Ground glass joints are checked to specifications and tested for leaks.

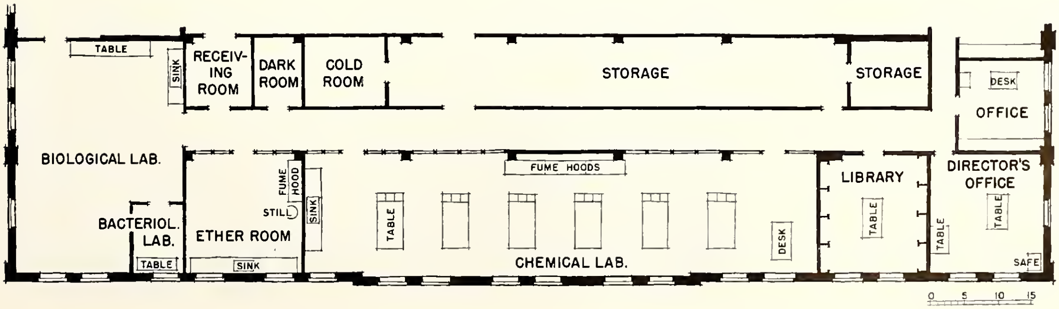
About 300 samples per day are checked by the staff of 14 people, five of whom are technically trained.

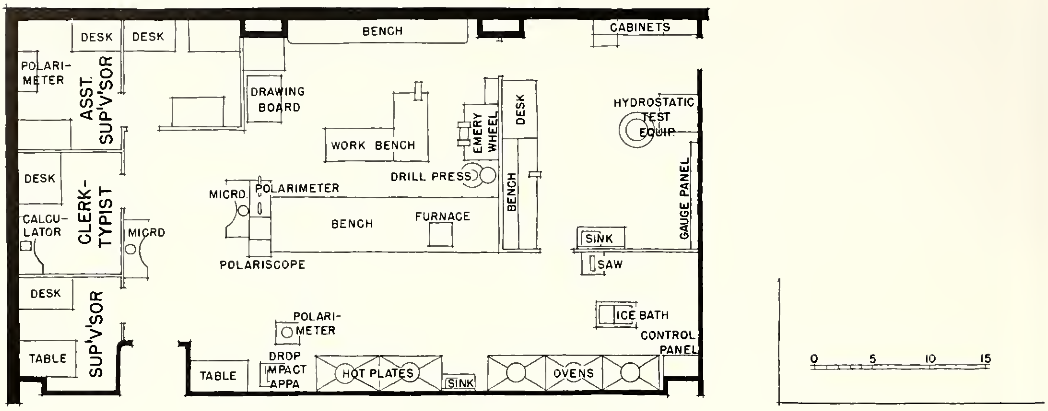
The floors of the laboratory are covered with rubber or composition tile. The entire ceiling is concrete as are two of the four walls; the other two walls are glass brick. Incandescent lighting is employed. The laboratory is well ventilated by filtered air. All heating operations are performed in hoods to carry off excess heat.

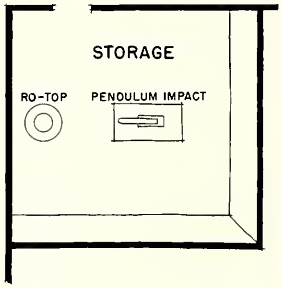
The laboratory is equipped with petrographic microscopes, binocular microscope, thermal shock ovens with automatic control, refrigerated cold bath, abrasive glass cutting saws, impact tester, polariscope for finding strains, high-pressure hydraulic pumps and tanks, vacuum pumps, annealing furnace with automatic control, five hoods and sieve shaker.

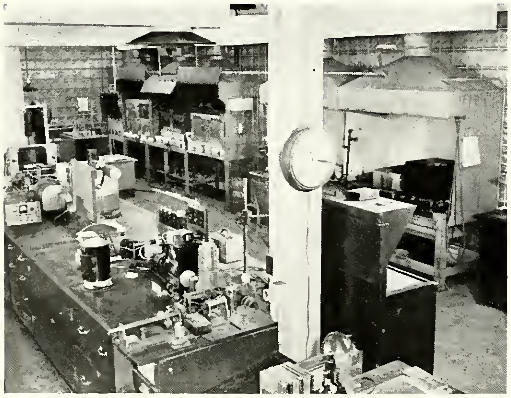
Figure III.13a and b, right and below, Food Laboratories. H. J. Heinz Company, Pittsburgh, Pennsylvania.





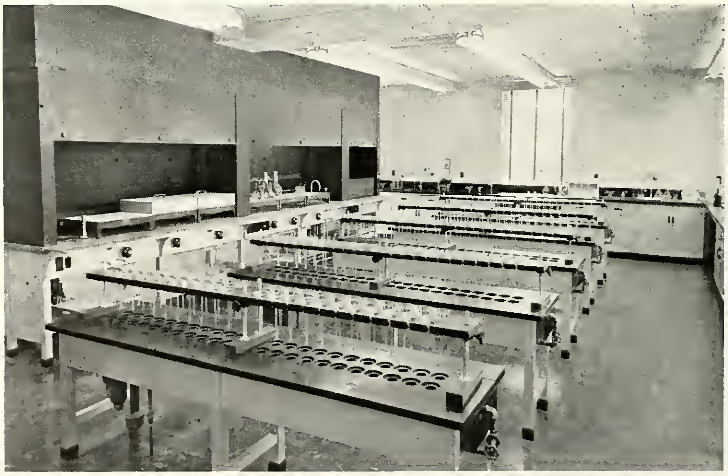






Figures III.14a and b, left and above, Glass Laboratories. Corning Glass Works, Corning, New York.

Figure III.15a, right, Nonferrous Metal Laboratories. Aluminum Company of America, Davenport, Iowa. Figure III.15b, far right, plan of the same laboratories.

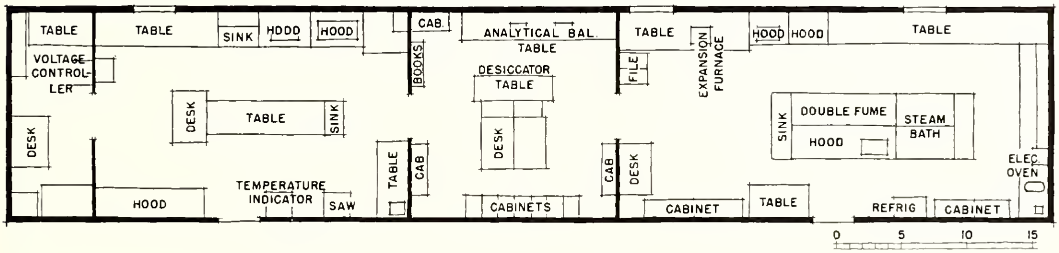


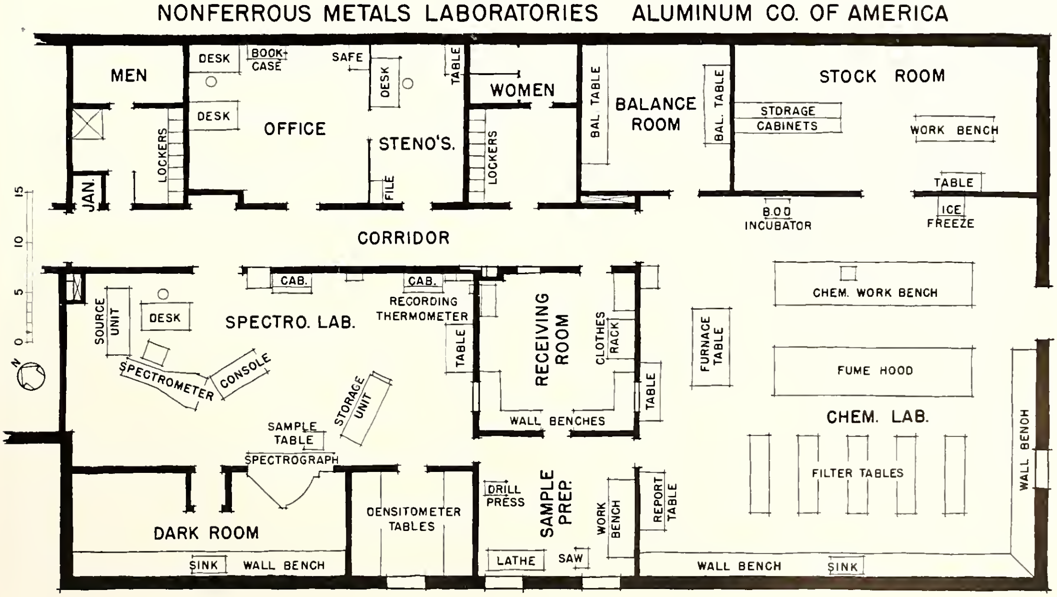
The laboratories of the Westinghouse Electric Company, Fairmont, West Virginia (figures III.16a and III.16b) have been designed for the quality control of glasses and the raw materials used in making them. In all they contain about 1,300 square feet, in the physical test laboratory, the chemical laboratory and the office.

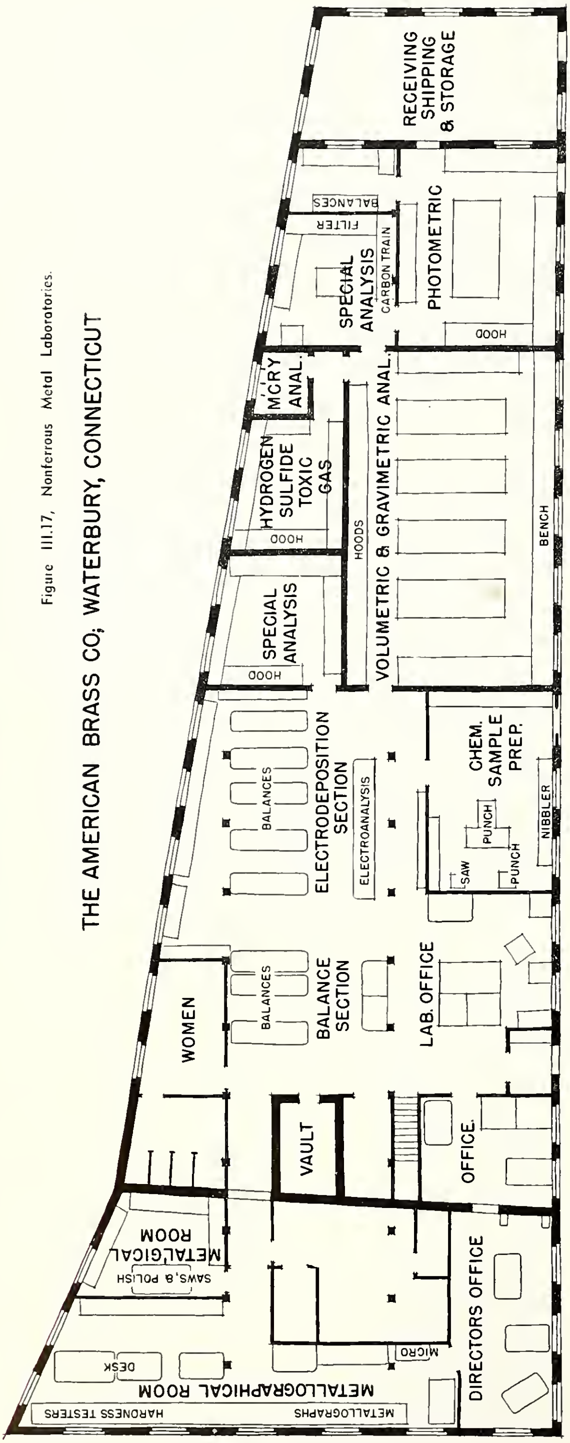
Most of the tests performed are of a physical nature such as density, sieve analysis, coefficient of expansion and softening point, although a number of chemical analyses are also made. The laboratory is staffed by three technically trained individuals who handle about six samples per day.

For the chemical analyses the laboratory is equipped with four fume hoods, two ovens, two muffle furnaces, steam baths, two analytical balances, sample grinder,

Figures III.16a and b, above and below, Glass Laboratories. Westinghouse Electric Company, Fairmont, West Virginia.







THE AMERICAN BRASS CO; WATERBURY, CONNECTICUT

Figure III.17, Nonferrous Metal Laboratories.

pH meter, hot plates, water still, photoelectric colorimeter, and two gas analyzers.

In the physical testing rooms the equipment includes petrographic microscope, binocular microscope, coefficient of expansion apparatus, softening point apparatus, sieve shaker, precision potentiometer, recorder-controller, optical pyrometer and abrasive cut-off saw.

The laboratories are partitioned off from larger plant space by glass windowed partitions. The floors are concrete and tile, the ceiling is plaster. The lighting is diffused incandescent while the ventilation is handled by fans. Some of the furniture is wood and some steel; tabletops are made of stone (for chemical work), plastic and glass for special purposes.

NONFERROUS METAL LABORATORIES

Figures III.15a and III.15b represent the most recently completed laboratory of the Aluminum Company of America at Davenport, Iowa. It is laid out along lines similar to other of the company's laboratories.

In addition to controlling the chemical analysis of a number of aluminum alloys, this laboratory also analyzes oils and lubricants, water, sewage and a wide variety of occasional samples. Alloy aluminum is analyzed for Cu, Si, Fe, Mn, Mg, Zn, Ti, Ni, Pb, Sn and Cr. All these elements can be determined either chemically, by photographic spectroscopy or by direct-reading spectroscopy so that the laboratory has three separate approaches and types of equipment for its work.

Oils and other lubricants are given these tests: flash point, fire point, saponification number, viscosity, staining characteristics, interfacial tension and or neutralization number. Water and sewage testing include determination of pH, hardness, turbidity, total solids, chlorine content, alkalinity, B.O.D. and/or nitrates.

The laboratory is staffed by about 15 people who handle about 200 samples per day and average about 1,500 determinations per day. Metal samples are brought to the laboratory by pneumatic tubes.

The entire laboratory occupies about 5,600 square feet of floor space. All floors are concrete covered with asphalt tile. The laboratory walls are glazed tile while the corridor and office walls are removable aluminum sheet partitions. All ceilings are covered with perforated aluminum acoustical tiles.

All the lighting is fluorescent and the entire laboratory is maintained the year around at 75°F and 40% relative humidity. Laboratory tables and hoods are stone. Steel tables with linoleum tops are used in spectrograph room.

All chairs, doors, door frames, window frames and venetian blinds are made of aluminum. Desks and storage cabinets are steel finished in aluminum.

The major items of equipment include a 2-meter grating spectrograph, densitometer, developing machine and excitation source; also available is a large direct-reading spectrograph and its excitation source; large fume hood, five filter tables, wall tables, five analytical balances, viscosimeter, centrifuge, combustion, water still; drill press, band saw and lathe for metal sample preparation.

The floor plan (figure III.17) shows the large and well laid out control laboratories of the American Brass Company, Waterbury, Connecticut, designed to analyze brasses and bronzes of many varieties as well as lead, water, oil, drawing and cutting compounds, coal, solders and fluxes, propane gas and analytical, metallurgical and corrosion studies for the research organization.

The following elements are determined: Cu, Zn, Pb, Fe, Si, P, Mg, Al, Be, Cr, Ni, Cd, Mn, As, Te, Sb, S, Co, and Ca. Under the heading of physical tests these laboratories perform micro and macro structure studies, tensile and elongation measurements, indentation and hardness determinations, shear and fatigue strength analyses, and torque strength studies.

In all, the laboratories handle about 200 samples per day and perform over 1,000 individual determinations per day. About 66 people are employed of whom about 27 are technically trained.

Some of the floors of the laboratories are mastic and some wood. The inside partitions are wood. Special attention is called to the large window area along the entire lengths and across both ends of the laboratories. The total floor space occupied is about 4,000 square feet. All lighting is fluorescent and all ventilation is forced filtered air except in the spectroscopy room where air conditioning is employed.

Most of the laboratory furniture is of wood construction with stone tops. Prescribed color dynamics were used in choosing paint colors in all the laboratories to reduce eye fatigue.

The major items of equipment employed are: seven fume hoods, a special perchloric acid hood, 16 analytical balances, five muffle furnaces, high-temperature furnace, pH meter, three filter photometers, electrometric titration apparatus, 250-spindle electro deposition apparatus, carbon determination train, grating spectrograph, quartz-prism spectrograph, ultraviolet spectrophotometer, two viscometers, chemical microscope, three micro-metallographs and four table microscopes.

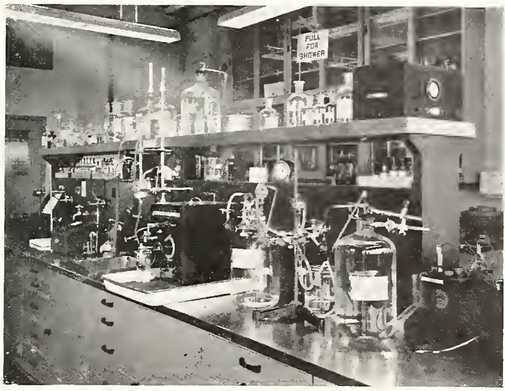
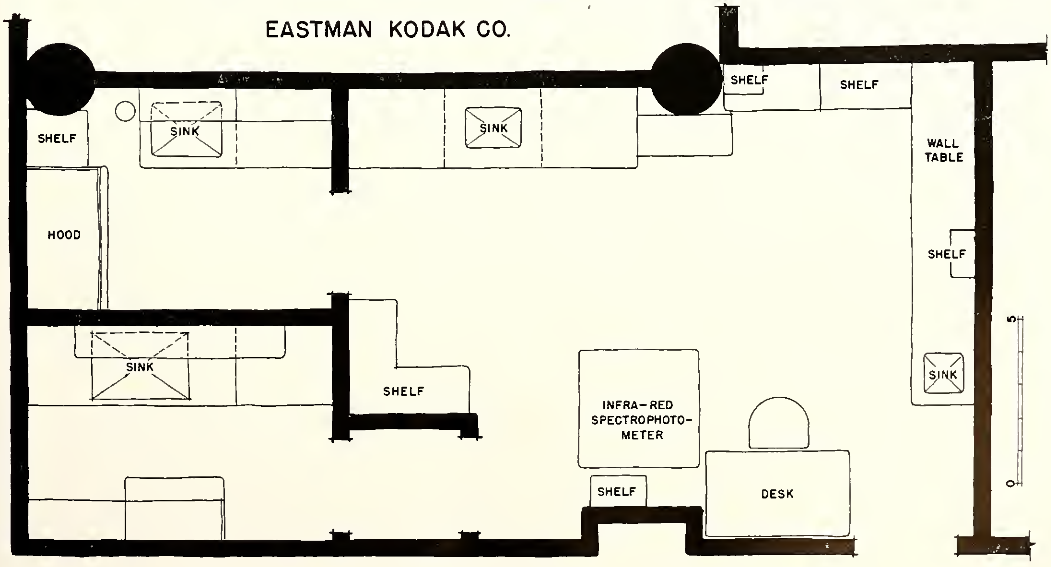


Figure III.18a, above, Organic Chemical Laboratories. Eastman Kodak Company, Rochester, New York.

ORGANIC CHEMICAL LABORATORIES

Figure III.18a shows one of the many quality control laboratories at the Kodak Park Works of the Eastman Kodak Company, Rochester, N. Y. As may be seen from the plans, figures III.18b and III.18c, it has been

Figure III.18b, below, floor plan of the same laboratories (see also figure III.18c on the next page).



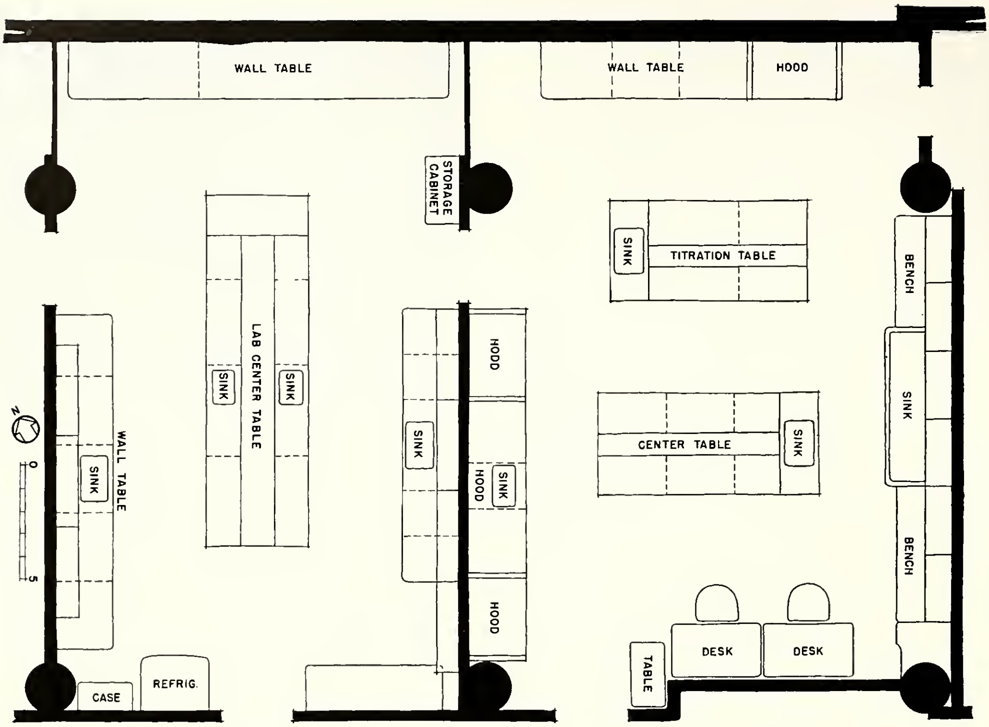


Figure III.18c, above, floor plan of the Organic Chemical Laboratories. Eastman Kodak Company, Rochester, New York

designed throughout especially for the control of developers, couplers and antifoggants employed in color photography.

About five samples are analyzed per day for a total of about 25 determinations. A staff of 15 includes some devoting only part of their time to analysis. Determinations are made of pH, ultraviolet absorption, visible light absorption, infrared absorption and solubility.

The floors of the laboratories are finished in asphalt tile while the ceilings are perforated metal acoustical tile. Partition walls are steel while glazed tile is used to line outside walls. Lighting, which is particularly important in the type of work performed, is 4500° fluorescent, 60% direct—40% indirect. Ventilation is by air conditioning and dust is removed by an electrostatic separator and oil filter. The laboratory furniture is made of steel with stainless steel tops.

Major items of equipment include a double-beam recording infrared spectrometer, double-beam recording ultraviolet and visible spectrometer, two prism spectrophotometers with hydrogen lamp sources, three glass-electrode pH meters, three analytical balances, oven, dropping mercury electrode apparatus, visual titration bench and automatic recording titrator.

PAINT LABORATORIES

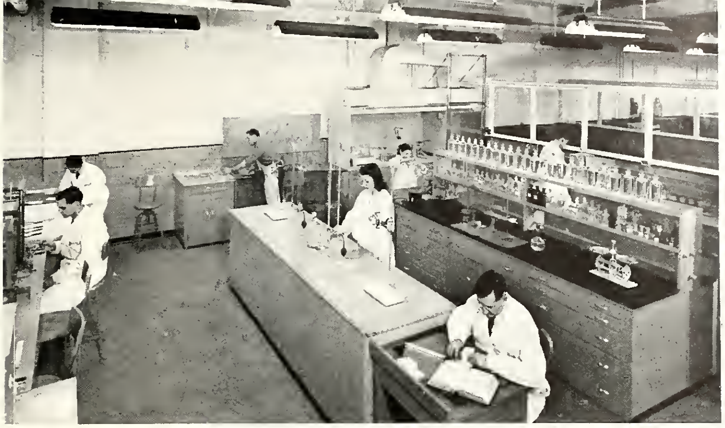
The laboratories of the Glidden Company, Cleveland, Ohio (figures III.19a and III.19b) are called upon daily to analyze both raw materials and finished paints, varnishes and lacquers of a wide variety of types. Both the physical and chemical characteristics of pigments, oils, resins, solvents and other chemicals are determined. Many performance tests such as weathering, hiding power, adhesion and drying time are necessary parts of the work.

The laboratories employ 15 people of whom eight are technically trained. They test about 120 samples per day from the receiving zone or processing areas which are both near by.

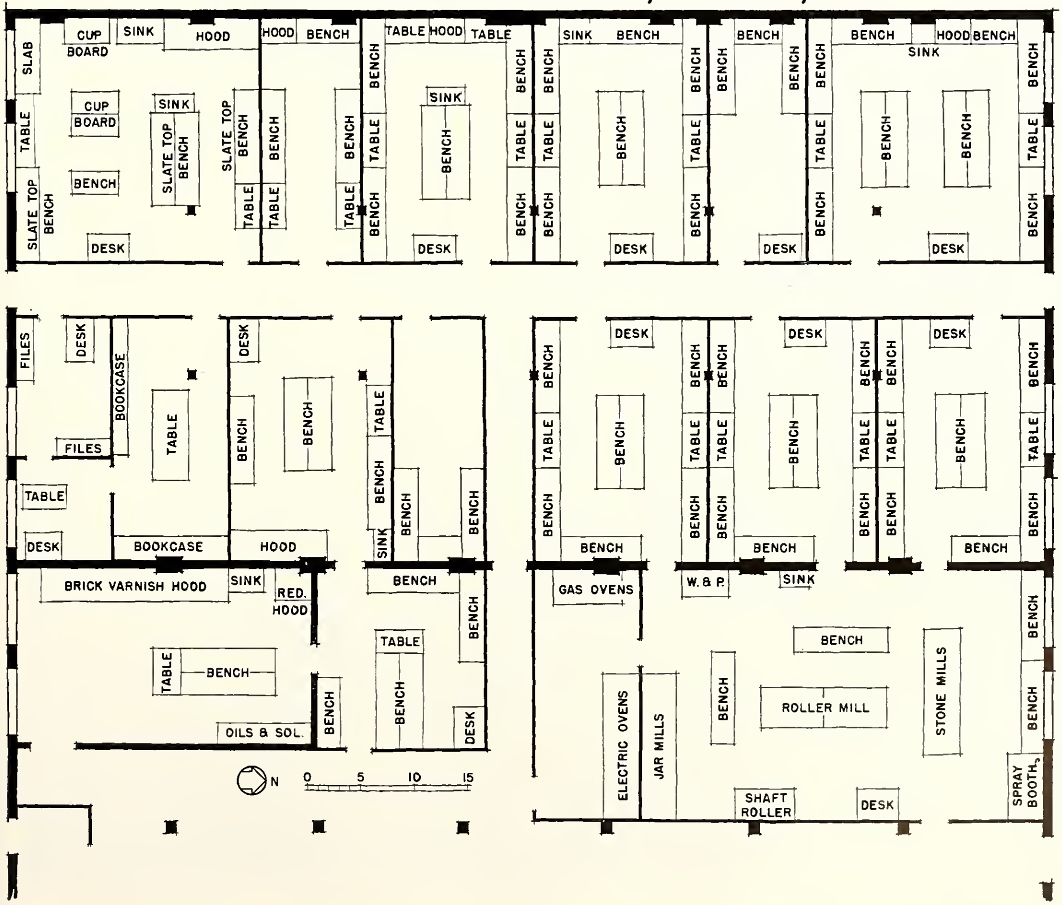
The total laboratory area is about 10,000 square feet. The floors are concrete, the ceilings concrete and gypsum block and the walls are brick and metal partitions. All lighting is fluorescent while the ventilation is by forced draft. Some laboratory tables are wood and some are metal; slate, metal and composition tabletops are used. The low glass partitions used give segregation without isolation or impeded ventilation.

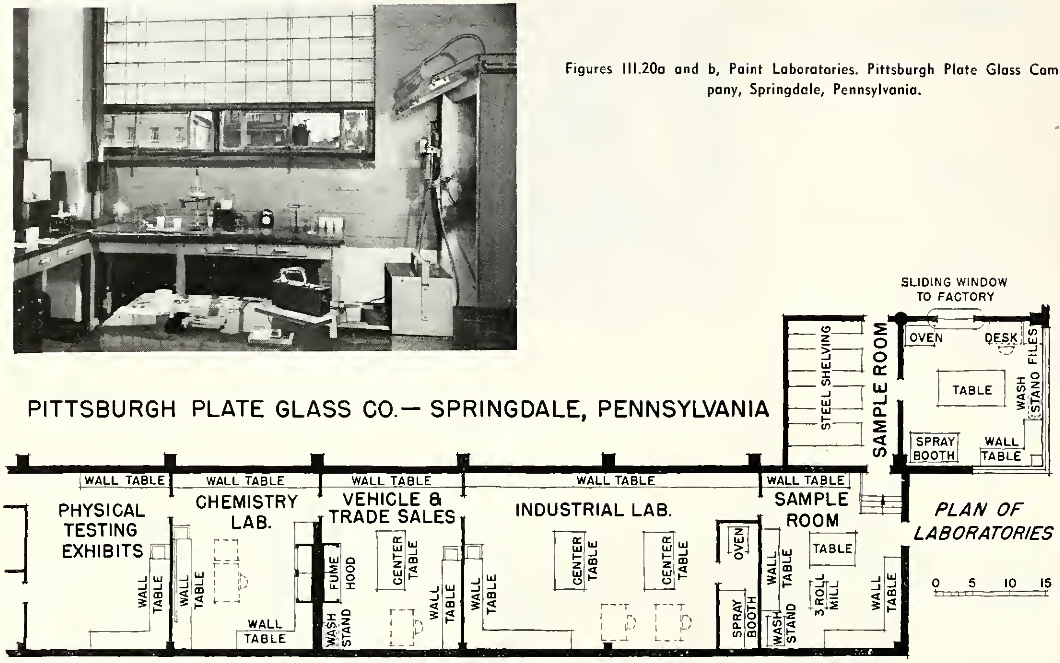
The laboratories are completely equipped for chemi-

Figures III.19a and b, Paint Laboratories. Glidden Company, Cleveland, Ohio.



PAINT LABORATORIES — GLIDDEN CO., CLEVELAND, OHIO





Figures III.20a and b, Paint Laboratories. Pittsburgh Plate Glass Company, Springdale, Pennsylvania.

cal analysis as well as physical tests, such as humidity, salt spray and low temperature; viscometers, abraders, hardness testers, film-thickness gauges, impact testers and glossmeters are employed.

The laboratories of the Pittsburgh Plate Glass Co., Springdale, Pennsylvania (figures III.20a and III.20b) are part of a new paint and varnish production unit and are designed to control the quality of raw materials such as pigments, oils, resins, solvents, and driers, various intermediate products and the finished paints, varnishes and enamels.

In analyzing pigments, determinations of color, tinting strength, oil absorption and percent of metal are made. Intermediate products are analyzed for percent total solids, color, weight per gallon, drying characteristics and viscosity. Finished products receive tests for fineness of grind, viscosity, weight per gallon, application characteristics, drying properties, gloss and color.

The laboratory is staffed by twelve people of whom seven are technically trained. They are called upon to analyze about 125 samples per day for a total of about 750 determinations.

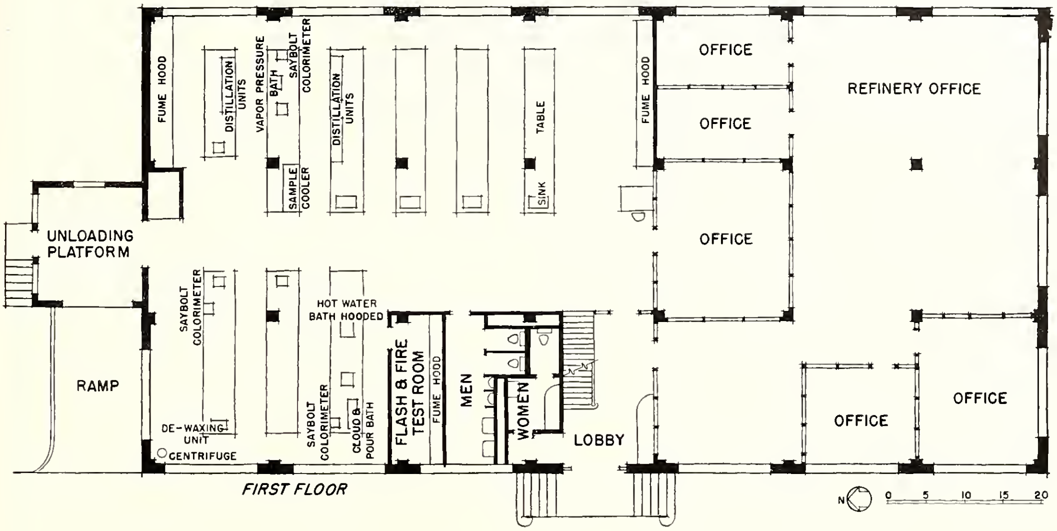
The laboratory floors are cement, the ceilings are covered with acoustical tile, the inside walls are hollow tile, the windows combine glass block with plate glass ventilating sash; all lighting is fluorescent. The laboratory furniture is wood with stainless steel tops except in the chemical laboratory where soapstone tops are used.

Among the more important pieces of test equipment are: two fume hoods, two spray booths, a small oven, two box ovens, two drill presses, a two-gallon laboratory can mixer, steel ball mill, double-tier jar mills, three-roll mill, microscope, constant-temperature water bath, analytical balance, two fineness gauges, three Ford cups, solvent distillation apparatus, centrifuge, 60° gloss meter, automatic muller, three gravity cups and roll coater.

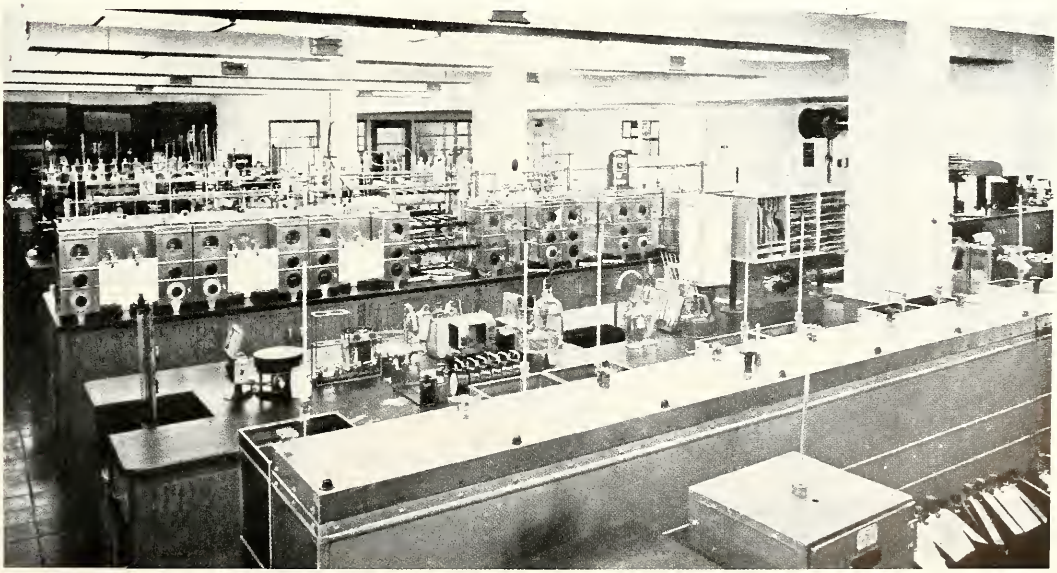
PETROLEUM LABORATORIES

The new Continental Oil Company laboratories in Ponca City, Oklahoma (figures III.21a and III.21b) are situated in the basement and ground floor and occupy about 6,700 square feet. They are outstanding examples of petroleum refinery control quarters.

The staff of 80 handles about 800 samples per day and performs about 2,100 individual determinations. Physical tests performed include: gravity, flash and fire points, cloud and pour points, color, viscosity, distillation, vapor pressure, emulsion, melting point, pene-



Figures III.21a and b, Petroleum Laboratories. Continental Oil Company, Ponca City, Oklahoma (see also figure III.21c on the next page).



tration, carbon residue, gum tests, corrosion, oil content of waxes, wax content of oils, low-temperature distillations and octane number determinations. Chemical determinations include: furfural, sulfated residue, Fe, Cu, Pb, Si, Ba, Ca, Zn, Fl, C, S, Cl, Al, Mg, HCl, KOH, NaOH, chlorides, sulfates, sulfites, sulfides, phosphates, phenol, diethanolamine, pH, water analysis, acidity, alkalinity, orocol, insoluble malter, aniline number, bromine number, iodine number, peroxide number, acid and base number, saponification number, mercaptans, tetraethyl lead and ash.

The concrete laboratory floors are finished with 8-inch red tile while the ceilings are cement-asbestos board. Walls have a tile wainscot and plaster above. All lighting is fluorescent and the entire laboratory is air conditioned; windows are glass block. Laboratory tables are wood with soapstone tops.

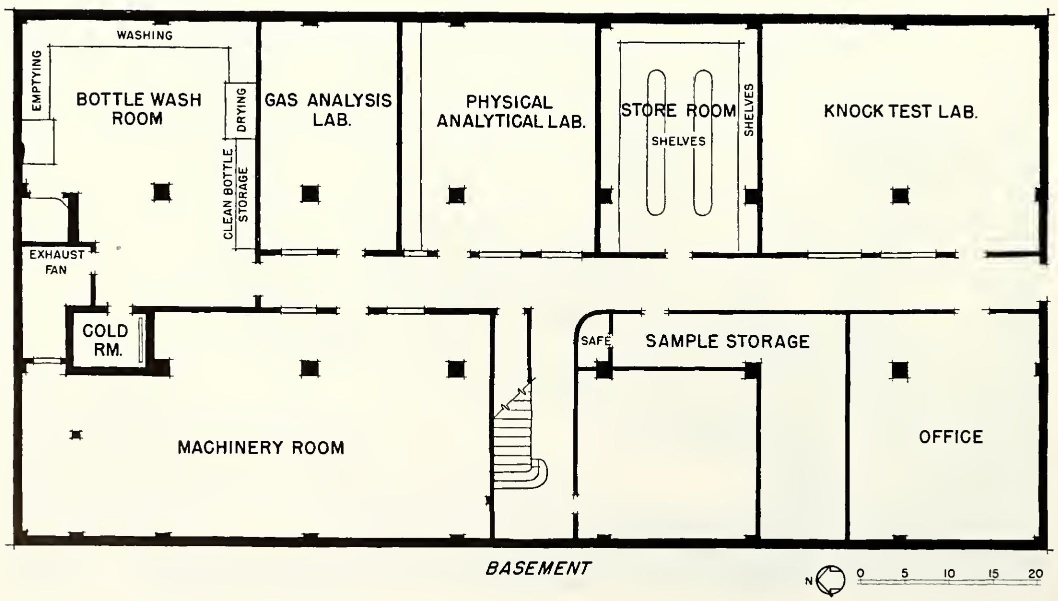
The major equipment items include: six analytical balances, six fume hoods, three ovens, two furnaces, seven viscosimeters, two refractometers, three pH meters, two electrometric titration apparatus, a micro Kjeldahl, dropping mercury electrode apparatus, six photoelectric colorimeters, spectrophotometer with flame attachment, three Saybolt chromometers, Union colorimeter, six constant-temperature water baths, (stainless steel baths built into cabinets with tops flush with laboratory tabletops), vacuum distillation unit, 20 gasoline distillation units, microscope, cloud and pour test bath, 20 flash and fire point units, low-temperature dewaxing bath, two electronic temperature indicators, three Torsion balances, three gum baths, copper-dish bath, two carbon residue apparatus, two electrolytic analyzers, six oxygen bombs, calorimeter, two penetrometers, motorized grease worker, wheel bearing grease tester, two centrifuges, four octane number engines, infrared spectrophotometer, two low-temperature distillation apparatus, four semi-automatic low-temperature distilling apparatus, four refrigerated sample cooling units and two electrical calculators.

Of particular interest are the use of fireproof paint inside the cabinets, the refrigerated walk-in cold room for storage of large volatile samples and the central refrigerating system in the basement for all cold baths.

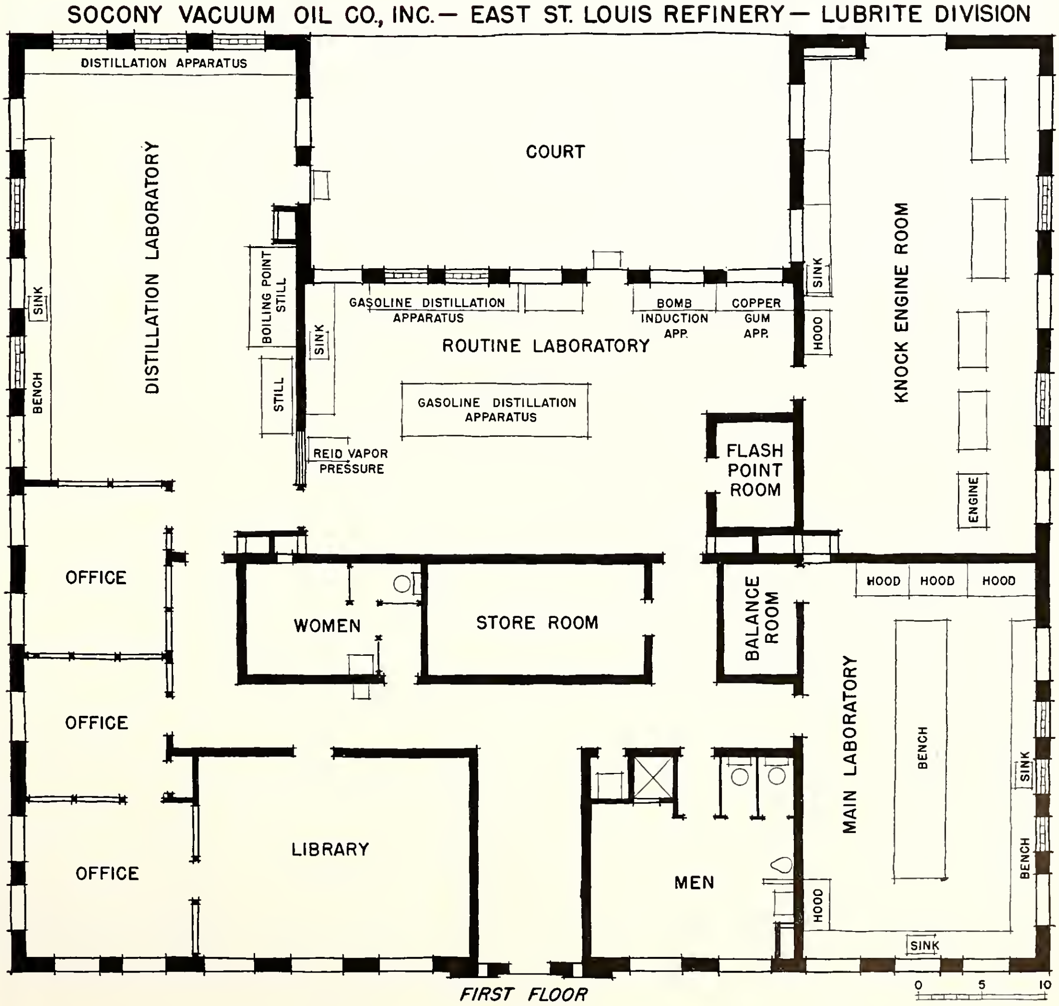
The laboratories of the Socony Vacuum Oil Co., Inc., East St. Louis, Illinois (figures III.22a and III.22b) occupy an entire one-story building of 5,700 square feet. They have been carefully planned to handle the quality control of various petroleum refinery products and the floor plan is worthy of careful study.

Tests performed include: octane ratings, vapor pressure, distillation, gravity, viscosity, pour point, flash point and bomb induction. The laboratory staff consists of 20 people of whom 10 are technically trained. About 50 samples are handled per day and an average of 250 determinations are performed per day.

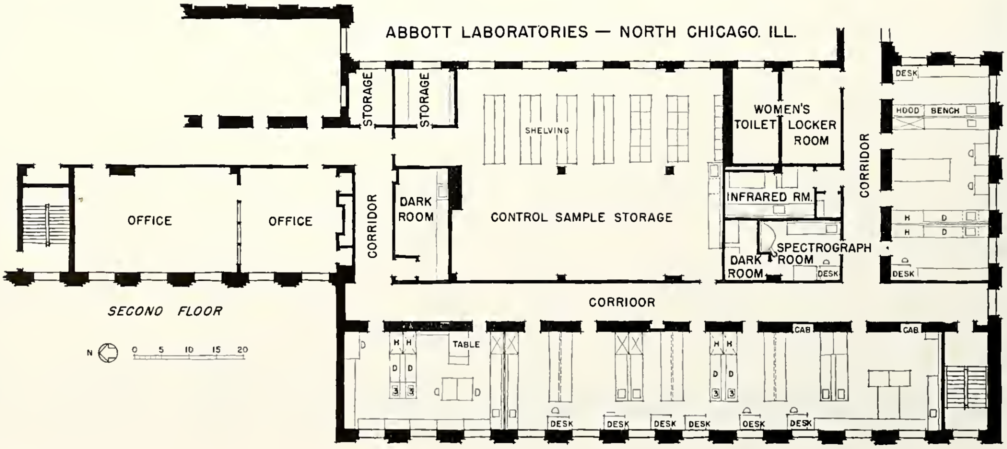
Figure III.21c, Petroleum Laboratories. Continental Oil Company, Ponca City, Oklahoma.



Figures III.22a and b, Petroleum Laboratory. Socony Vacuum Oil Company, Inc., East St. Louis, Illinois.



Figures III.23a and b, Pharmaceutical Laboratories. Abbott Laboratories, North Chicago, Illinois.



The entire laboratory floor is concrete covered with asphalt tile; all ceilings are finished in acoustical tile, an extra heavy grade being employed in the Knock Engine Room. All walls are glazed tile, all lighting is fluorescent and the ventilation is forced draft. Laboratory tables are wood with stone tops. Samples are brought to the laboratory by a sampler who travels by scooter to all parts of the refinery. Samples after analysis are stored in a separate building.

The major items of equipment include: four analytical balances, pH meter, combustion furnace, muffle furnace, fuel calorimeter, gas calorimeter, electrometric titration apparatus, five fume hoods, Saybolt chromometer, refractometer, kinematic viscosimeter, Saybolt viscosimeter, four knock engines, two six-unit distillation apparatus and bomb induction apparatus.

PHARMACEUTICAL LABORATORIES

The control laboratories of Abbott Laboratories, North Chicago, Illinois (figures III.23a and III.23b) have been laid out to test and analyze batches of various drugs and chemicals used in pharmaceutical manufacturing, as well as to perform assays on the finished pharmaceutical products. These products vary widely in scope and include syrups, elixirs, tinctures, solutions for parenteral administration, ointments and suppositories, capsules, vitamin preparations, antibiotics, anesthetics, hypnotics and antiseptics. The test methods employed included USP methods, NF methods and special methods developed as a result of research.

Samples from various parts of the plant are brought to the laboratories by messenger and distributed to various workers. About 80% of these workers are technically trained in either chemistry or pharmacy, the remaining personnel being technicians and stenographers. Most samples require two or more different determinations and, after test, are retained in steel drawers for five years.

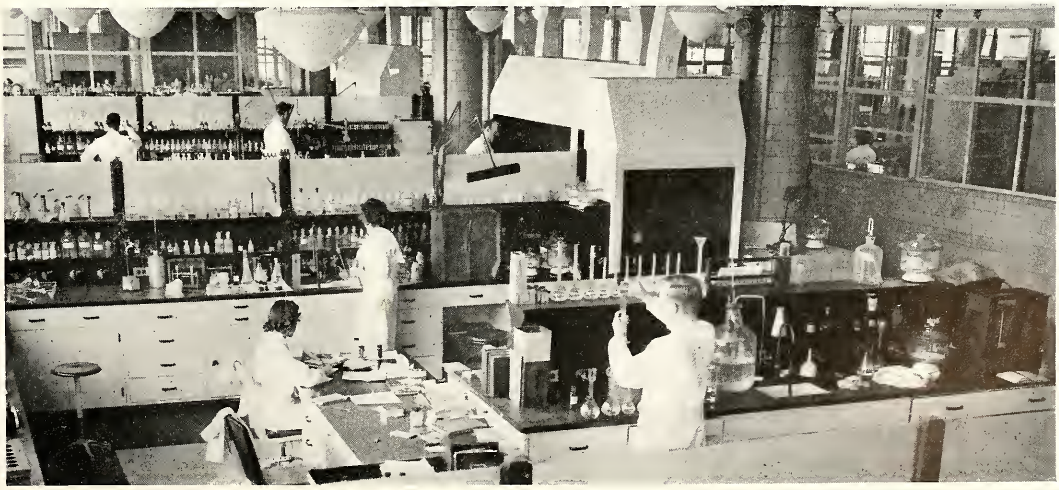
The laboratories occupy over 10,000 square feet on the second floor of a large building. The floors are finished in asphalt tile; the ceilings are plastered; inside walls are glazed terra cotta. All lighting is fluorescent and ventilation is by forced circulation except in the infrared spectrographic and emission spectrographic rooms where air-conditioning is employed. The laboratory furniture is steel with composition tops.

Major equipment items include fume hoods, analytical balances, pH meters, ovens, photoelectric colorimeters, photoelectric fluorometers, refractometer, polarimeters, viscosimeter, micro Kjeldahl apparatus, deaminizing apparatus, particle-size analyzer, muffle furnaces, emission spectrograph and densitometer, quartz spectrophotometer and infrared spectrophotometer.

The Parke-Davis Company's laboratories in Detroit, Michigan (figures III.24a and III.24b) are excellent examples of good laboratory design to handle the analysis of raw materials, manufactured intermediates and finished products for a large pharmaceutical manufacturer.

A staff of 31, 21 of whom have technical training, is

Figure III.24a, Pharmaceutical Laboratories. Parke-Davis Company, Detroit, Michigan.



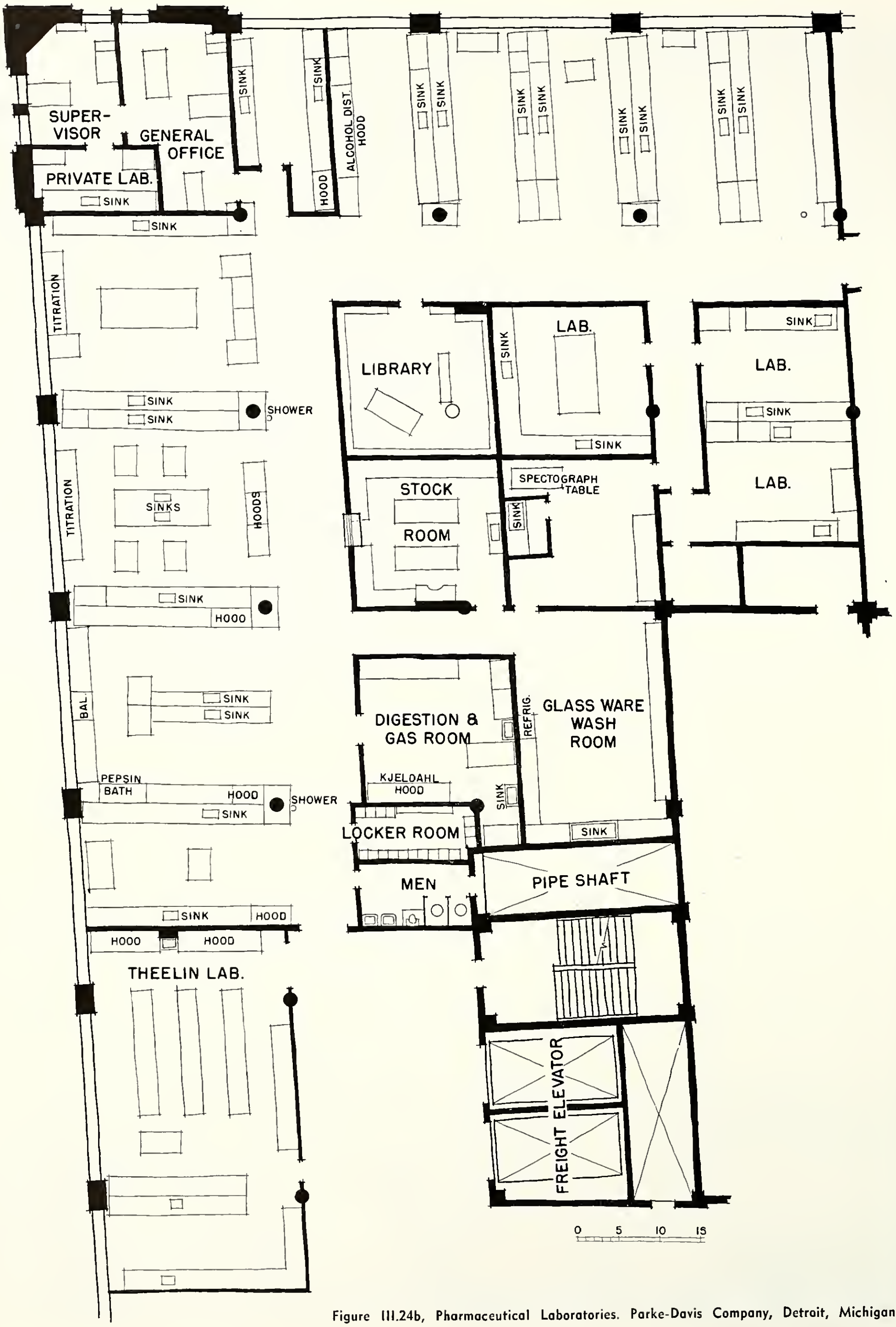


Figure III.24b, Pharmaceutical Laboratories. Parke-Davis Company, Detroit, Michigan.

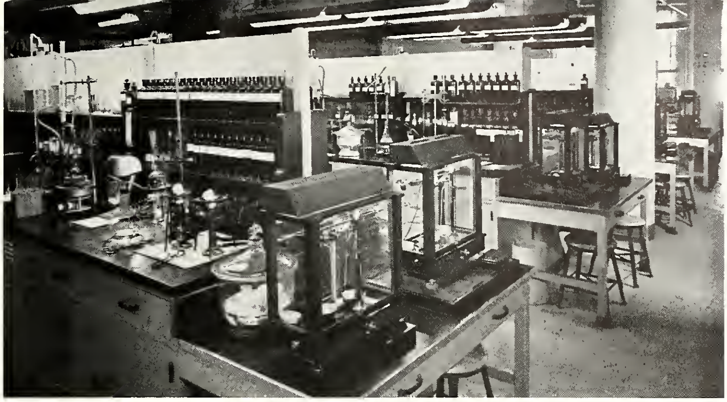


Figure III.25a, right, Pharmaceutical Laboratories. Sharp & Dohme, Inc., Philadelphia Pennsylvania. Figure III.-25b, below, plan of the same laboratory (see also figure III.25c on the next page).

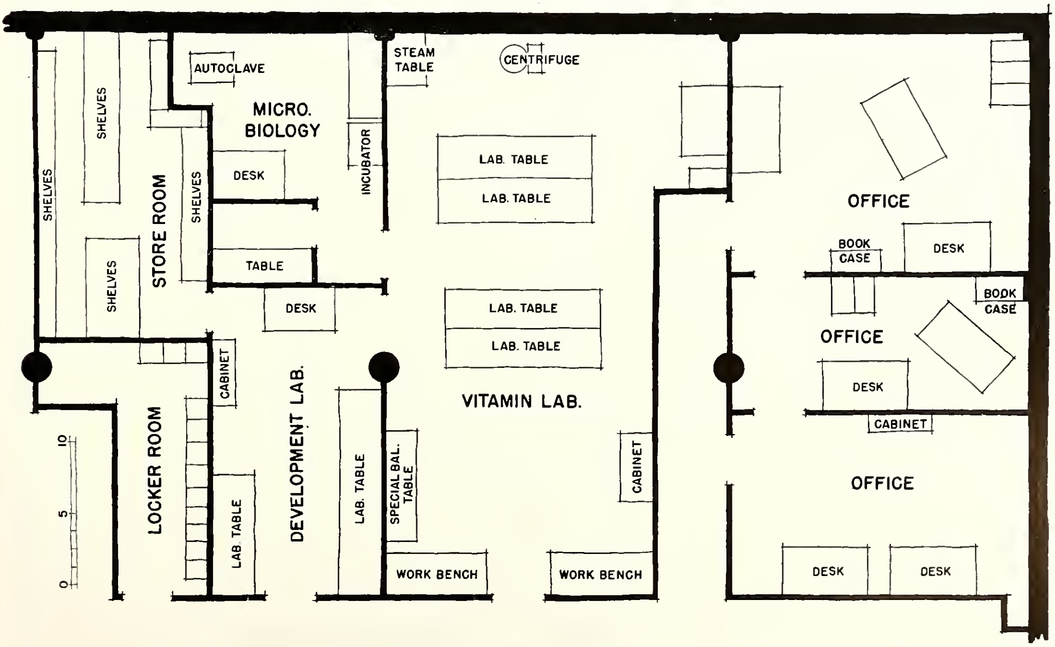
called upon to analyze about 85 samples per day and in doing so, performs about 425 individual determinations.

The variety of tests and assays for purity are numerous due to the large number of materials and products tested. The staff also performs research and development work on better assay methods and new methods for new products. Such tests as biochemical and physiological (employing animals), bacteriological and sterility are performed in another laboratory elsewhere in the plant.

The laboratory area here described occupies about 4000 square feet. The ceilings of the laboratories are painted concrete while the walls are glazed tile and glass partitioning. The general lighting is incandescent while the ventilation is by forced circulation. The illustration shows a unique part of one of the large analytical areas which is divided into open-type laboratories by frosted glass partitions extending half way to the ceiling, permitting maximum light and ventilation. All laboratory furniture is steel with treated wood tops.

The equipment employed includes: 16 fume hoods, two refractometers, grating spectrograph, four high-vacuum pumps, quartz spectrophotometer, penetrometer, four pH meters, seven ovens, three high-temperature ovens, four vacuum ovens, three microscopes, four photoelectric colorimeters, electrolytic analyzer, macro and micro Kjeldahl units, 14 analytical balances, two combustion furnaces, two electrometric titration apparatus, viscosimeter, spectrophotometer, polarimeter, five furnaces and manometric gas apparatus.

The laboratories of Sharp & Dohme, Inc., Philadelphia, Pennsylvania (figures III.25a and III.25b) have been carefully laid out to assay all pharmaceutical



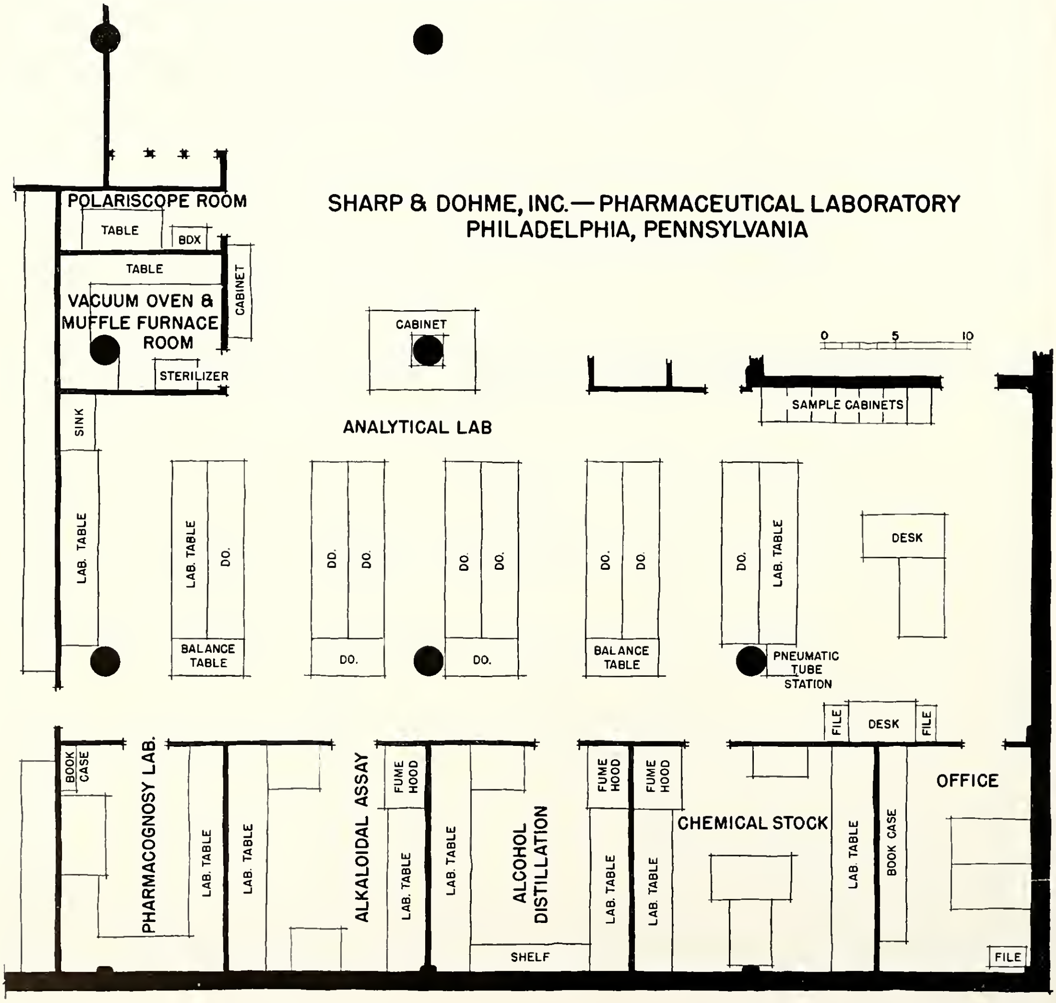
raw products employed in the plant as well as to assay finished products for active ingredients, purity and certain vehicles, and to determine the identity and physical characteristics.

The staff of 32, of whom 24 are technically trained, handles about 60 samples per day, averaging 240 individual determinations.

The laboratories cover about 4,600 square feet of floor space, all of which is finished with asphalt tile; the ceilings are concrete. Glass and composition board are used for partitions; all lighting is fluorescent. Samples are brought to the laboratory by messenger and pneumatic tubes, and, following test, are held for 5 years. Laboratory furniture is steel, some with wood tops and some with impregnated stone tops.

The major items of apparatus employed include nine chain-type analytical balances, a quartz-prism spectrophotometer, photoelectric fluorimeter, three pH meters, refractometer, visual colorimeter, photoelectric colorimeter, falling-ball viscosimeter, rotating-cup viscosimeter, Saybolt viscosimeter, penetrometer, surface tensiometer, two microscopes, moisture meter, electrometric titration apparatus, vacuum oven, high-vacuum pump, two incubators, autoclave, three muffle furnaces, three steam tables, centrifuge, six ovens, forced-draft oven, shaking machine, sieve shaker, pipette washer, cutting mill, six-unit Kjeldahl apparatus, eight-unit titration table, torsion balance and a five kilo scale.

Figure III.25c, Pharmaceutical Laboratories. Sharp & Dohme, Inc., Philadelphia, Pennsylvania.



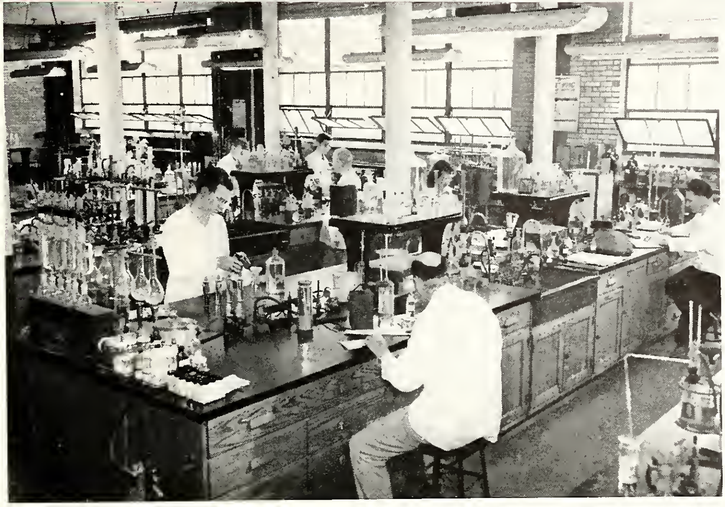


Figure III.26, Plastic Laboratories. Dow Chemical Company, Midland, Michigan.

PLASTICS LABORATORIES

Due to the wide diversity of products produced by the Dow Chemical Company, Midland, Michigan (magnesium, plastics, inorganic compounds, insecticides, organics, etc.) the control laboratories (figure III.26) are numerous and decentralized to keep control near the scene of production.

We illustrate here but one of the many different laboratories used for control work. The organization has about 500 people in laboratory work and over half of these are technically trained.

Some of the analyses performed in this laboratory include melting point determinations, clinical tests, nitrogen determinations, extractions, titrations and filtrations.

The laboratory is sprinkled as a fire-prevention measure. It uses wood furniture with stone tops. The walls are brick and the lighting is fluorescent.

RUBBER LABORATORIES

The Geon Division of the B. F. Goodrich Chemical Company in Louisville, Kentucky has two quality control laboratories (figures III.27a and III.27b) located in different parts of the plant. They control the finished polyvinyl materials as well as such raw materials as various hydrocarbons and acids, and plasticizers, like various metal organics.

The combined staff totals 40, of whom 11 are technically trained, performs about 3,200 individual determinations per day on 1,200 samples. These tests include screen analyses, electrical resistivity tests, per cent whiteness, relative molecular weight, moisture content and heat stability.

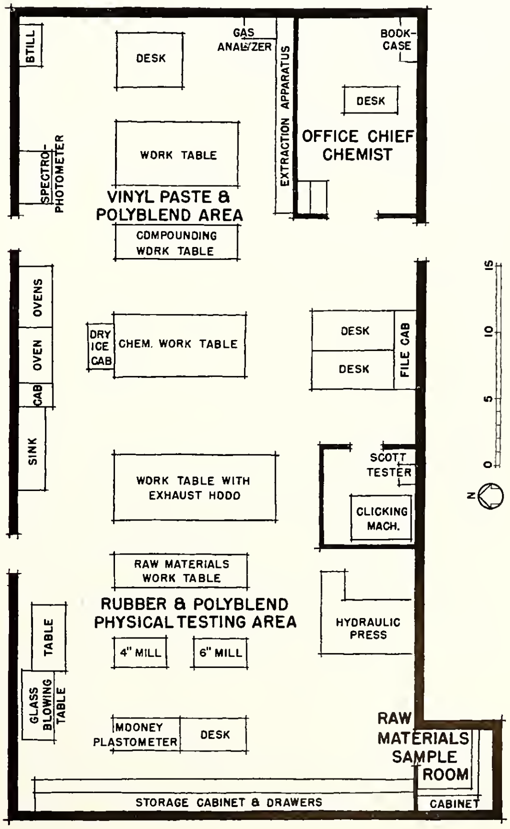


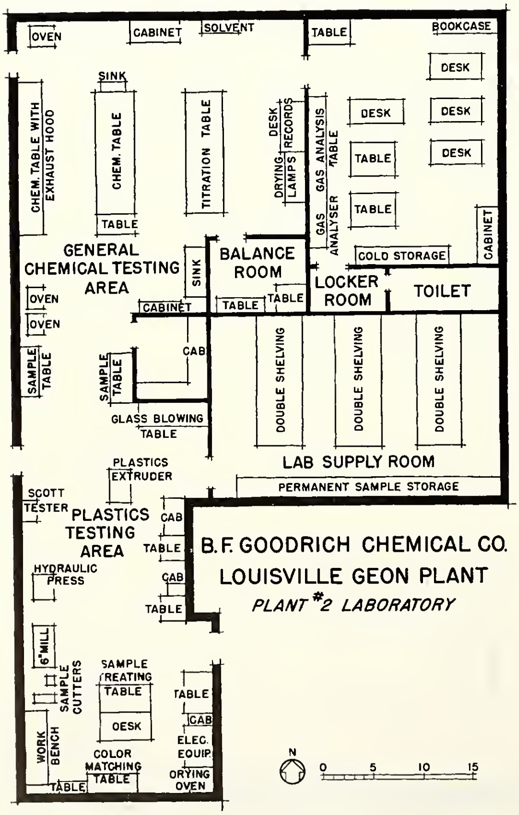
Figure III.27a, Rubber Laboratories. B. F. Goodrich Chemical Company, Louisville, Kentucky (see also figure III.27b on the next page).

The laboratories occupy about 4,600 square feet and have concrete floors, plaster ceilings and tile wainscoted walls. The ventilation is by forced draft and the lighting is fluorescent. Two mills are vented by an exhaust system combined with the exhaust system of the fume hoods.

The laboratories are equipped with the following major equipment items: 18-inch ram hydraulic press, 12-inch ram hydraulic press, volume resistivity apparatus, seven laboratory ovens, five constant-temperature baths, mechanical convection oven, refractometer, five analytical balances, large gas analysis apparatus, three Orsat gas analyzers, two tensile strength testers, three mills (two temperature controlled), quartz spectrophotometer, six pH meters, seven fume hoods, two muffle furnaces and a plastic extruder.

The quality control laboratories of the Naugatuck Chemical Division of the U. S. Rubber Company, Naugatuck, Connecticut (figures III.28a and III.28b) are located on the first floor of a three-story building. The upper floors are devoted to physical testing and research respectively. The Control Laboratory illustrated occupies about 12,000 square feet and is principally a finished product control center although it also checks raw materials, work in process and does certain analytical work for the research group upstairs. Analytical results are sent to the shipping room via "Telautograph".

Figure III.27b.



The lab is divided into four major areas: one devoted chiefly to testing latex and water dispersions of rubber and rubber-like materials, the chemical analysis area, the routine finished product test area and the area devoted to testing samples from the research group.

Among the tests performed by the 35 people employed to handle about 2,250 samples per day are: nitrogen, sulfur, chlorine, phosphorus, ash, moisture, sieve analysis, solids, viscosity, pH, specific gravity, refractive index, many varied colorimetric determinations, acid number, saponification number, distillations, optical rotation, oxidation-reduction titrations, chromatographic separations and ultraviolet absorption measurements.

The concrete floors of the laboratories are covered with asphalt tile while the ceilings are painted concrete. The walls are painted brick; the lighting is fluorescent throughout and the ventilation is forced draft, tempered in winter. Laboratory tables are wood with stone tops and sinks; desks, chairs and stools are steel.

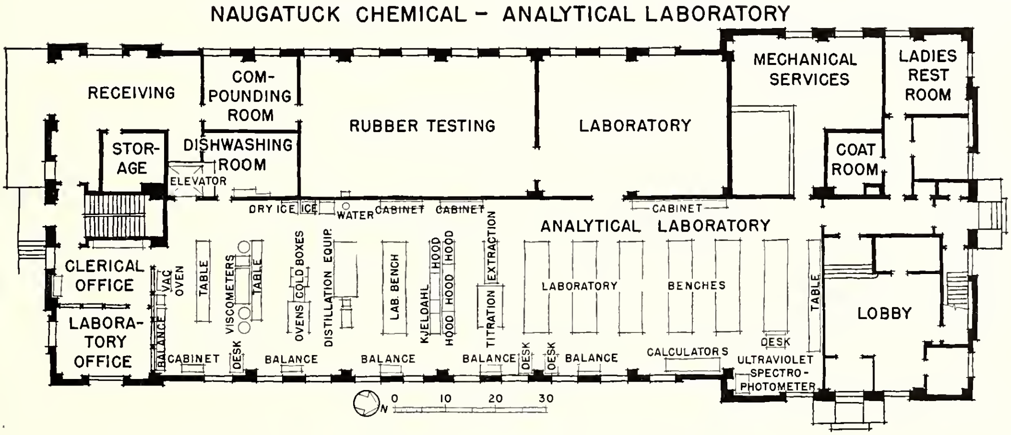
The equipment employed includes: eight analytical balances, six gravity-convection ovens, three forced-draft ovens, a vacuum oven, three rotating-cylinder viscometers, Saybolt viscometer, two pH meters, two photoelectric colorimeters, quartz spectrophotometer, 12-unit Kjeldahl apparatus, oxygen-bomb calorimeter, special titration table, four fume hoods, two muffle furnaces with automatic control, three low-temperature chambers, 45-unit extractor, hydraulic press, refractometer, polariscope, dropping mercury electrode apparatus, particle size apparatus, amino nitrogen apparatus, flow tester for plastics, moisture vapor transfer apparatus.

STEEL LABORATORIES

The laboratories of the Allegheny-Ludlum Steel Corporation, Brackenridge, Pennsylvania (figures III.29a and III.29b) are outstanding examples of fine design and layout for the 24-hour per day chemical analysis of plain and alloy steels of wide variety and control of the raw materials used in their manufacture.

The following are the more frequently determined elements: C, Mn, P, S, Si, Cr, Ni, Mo, Cb, Ti, Cu, W, Al, V, Sn, Co and N. The staff of 71, of whom 10 are technically trained, handles about 325 samples per day and has an average daily output of about 1,450 determinations. Samples are stored for 18 months after analysis.

Figures III.28a and b, Rubber Laboratories. Naugatuck Chemical Division, U. S. Rubber Company, Naugatuck, Connecticut.



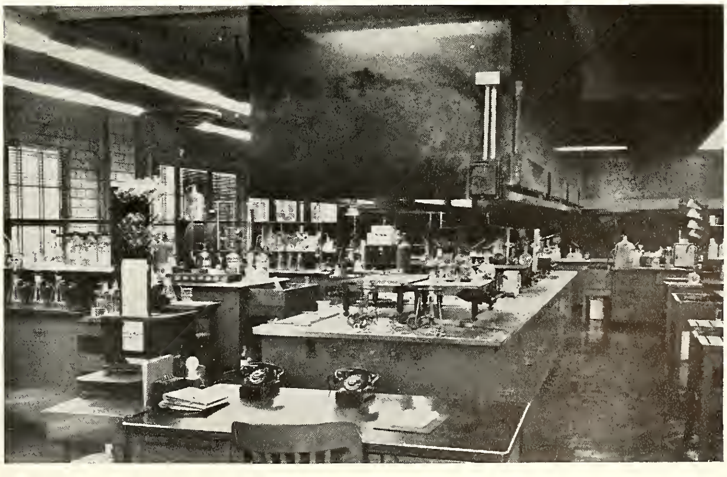


Figure III.29a, Steel Laboratories. Allegheny-Ludlum Steel Corporation, Brackenridge, Pennsylvania (see also figure III.29b on the next page).

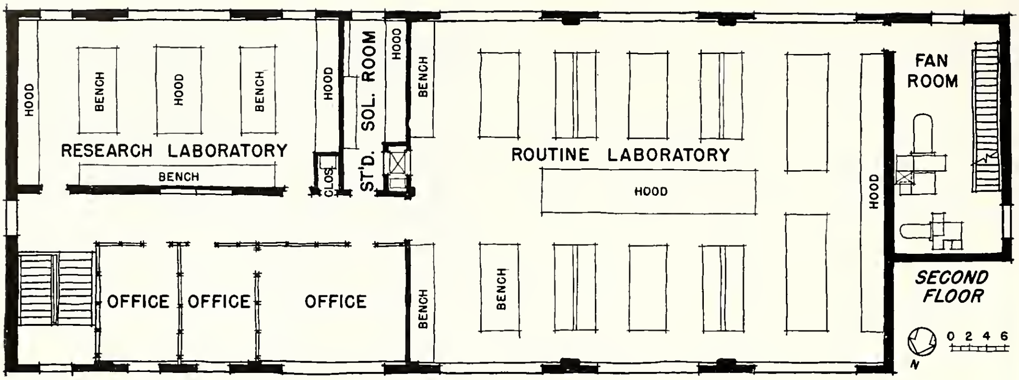
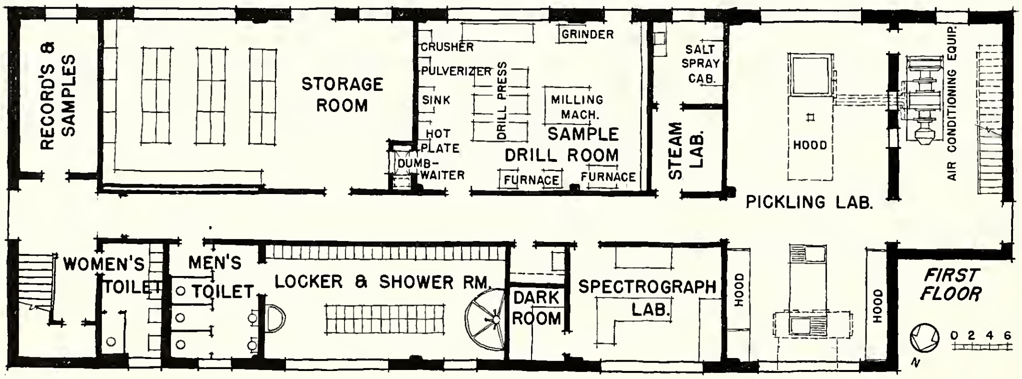


Figure III.29b, Floor plans of Steel Laboratories, Allegheny-Ludlum Steel Corporation, Brackenridge, Pennsylvania.



The laboratories occupy a total of 9,000 square feet on both floors of a specially designed building. The concrete floors are covered with asphalt tile; the ceilings are plaster finished with acid-proof paint; the walls are ceramic tile. All lighting is fluorescent and incoming air is filtered and tempered. Air is exhausted by the unique center-of-the-room, open-on-all-sides fume hood which appears in the illustration. The laboratory tables are steel with stone tops and stone sinks.

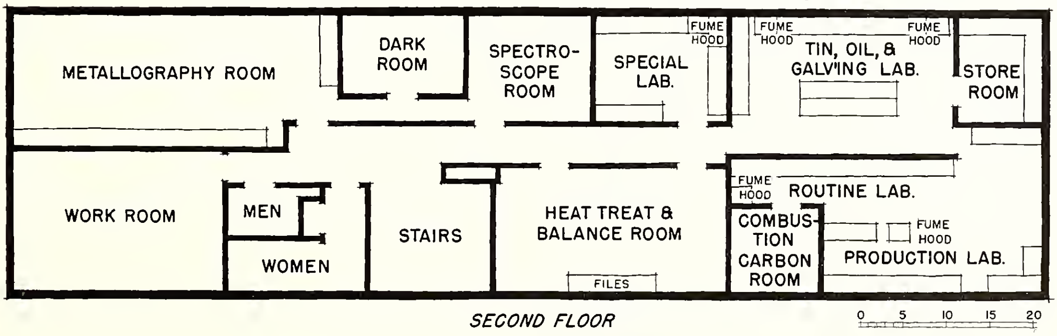
Samples are prepared on the first floor and sent to the second floor via a dumb waiter. Analytical results are sent to the melting department via "Telautograph". Distilled water is distributed to all sinks in tin-lined copper pipe from the storage tank in a penthouse.

Among the principal equipment items are: a spectrograph, two unique fume hoods, 12 analytical balances, two ovens, viscosimeter, two photoelectric colorimeters, vacuum fusion apparatus, three combustion furnaces, pH meter, two potentiometric titration apparatus, two muffle furnaces, six-unit electrolytic analyzer, and three micro Kjeldahl apparatus.

The Granite City Steel Company's laboratories in Granite City, Illinois (figures III.30a and III.30b) are of unique design and construction, and are examples of what can be done with a building situated in the heart of a busy steel plant. They control the quality of plain carbon steel and pig iron and its raw materials as well as checking the quality of certain refractories and fuel oils.

A staff of 21, working on a 24-hour per day basis, analyzes about 200 samples for 800 constituents daily. The samples arrive via pneumatic tubes and results are sent back to the melters by "Telautograph". Analyses are made for C, Mn, P, S, Si, Cu in steel; fuel oil, lime-

Figures III.30a and b, Steel Laboratories. Granite City Steel Company, Granite City, Illinois.



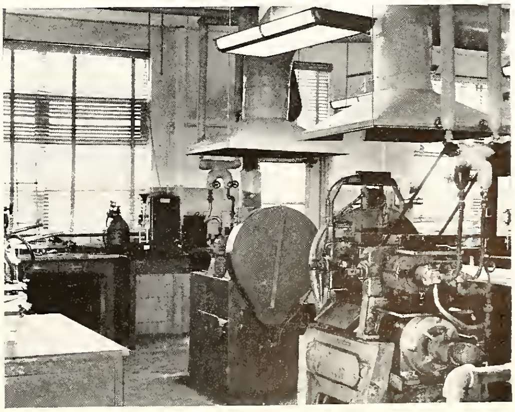
GRANITE CITY STEEL CO. — NEW LABORATORY LAYOUT

SECOND FLOOR

stone, ferro alloys, tinplate and galvanized materials are also checked.

The entire building is sealed, having glass block sections to admit light. All laboratories are air conditioned being fed with dust-free tempered air the year around. The concrete floors are covered with asphalt tile, the ceilings are treated with acoustical title; all light is fluorescent. Laboratory furniture is wood with stone, stainless steel and pressed wood tops, each used for different functions.

The laboratories are equipped with these major items: eight analytical balances, five combustion furnaces, two muffle furnaces, drying oven, fume hoods, pH meter, two volumetric carbon and sulfur determinators, three gas analyzers, oxygen bomb calorimeter, centrifuge, five gallons/hour water still and two tin deplaters.



SECTION 2: Details and Description of an Analytical Control Laboratory

B. L. Clarke • A. S. Doniger • R. N. Boos

Merck & Co. Inc., Rahway, New Jersey

Industrial analytical control laboratories vary in size and in function to a large degree. Depending upon the type and size of the operation controlled, the laboratory will range in size from a single room, or even a corner of a factory, to a large building housing many specialized units.

A small one-man unit may carry on simple essential quality control. In contrast, a large control organization will be involved in a highly complex function, with responsibility for establishing methods, testing for identification and quality, exercising statistical control of production, and a great many other duties associated with assurance of proper quality control. Such an installation will require a well-engineered layout and facilities for efficient operation. In a large chemical plant, it is not unusual to have specialized groups performing inorganic, organic, microanalytical and microbiological control work, employing varying types of apparatus and instruments, all under a single roof.

LARGE-ROOM VS. SMALL-ROOM LABORATORIES

In all cases where specialized work is required of an analytical unit, it is desirable to place it in a special laboratory. Laboratory arrangement may be made according to the requirements of the special equipment, and personnel will have an atmosphere suitable for the accomplishment of their special function. A study of a number of industrial laboratories reveals that 100 to 200 square feet should be allotted for each individual. The larger figure is preferred. Small laboratories, with dimensions of 20'0" by 20'0", containing facilities for two chemists, have proved to be the most functional in the opinion of the writers.

On the other hand, large-room analytical laboratories may be favored over the equivalent number of small laboratories, where great amounts of analytical work are to be produced and many chemists and technicians accommodated. The large-room laboratory may be administered with relatively greater efficiency in supervision and general economy. However, special problems such as ventilation, lighting, and the accessibility of common equipment are created by the large-room laboratory.

Laboratory planners will study with profit the descriptions of recent industrial and academic laboratories. In the past two decades, and especially as a result of war research activities, much progress has been made by industrial engineers in laboratory design and in the production of unit or module laboratory equipment and furniture. The detailed descriptions of up-to-date laboratories to be found on pages 274 to 387, may supply additional useful information.

LABORATORY PLANNING

The design of an analytical control building should be the result of the collaboration of architect and chemist, the architect interpreting and planning along the lines laid down by the persons who must work in the laboratories. The chemist should concern himself mainly with the three basic problems of analytical control laboratory design: 1. the selection of the units of the laboratory, the work table and the furniture required per individual, 2. the amount of space to be allotted per individual, including the arrangement of the unit with relation to general shared equipment and to service rooms, 3. the general utilities such as light, power, heat, steam, vacuum, compressed air, distilled water, etc., required for the unit. Ventilation is of special importance in the analytical laboratory building. It will be well to consult a specialist in this field to obtain the best system for individual needs. Once these three phases of the design are decided, the architect can begin to plan how the utilities will be grouped and supplied.

The analytical building will require service rooms such as glassware-washing facilities, oven rooms, storerooms for equipment and glassware, stock rooms, sample storage rooms, constant-temperature rooms, library, offices, conference rooms, janitor's storerooms, etc. In order to plan a useful building it will be necessary for the chemist and architect to come to a complete understanding of the technical requirements of the particular operation and to plan for the immediate as well as the future use of the analytical control building.

The following description of the analytical laboratories of Merck & Co., Inc., will prove of interest to planners of small and large scale analytical operations, in that both the large room and the two-module room are being successfully employed. These laboratories were designed according to the ideas of the chemists who were to work in them; the industrial engineers who evolved the plans collaborated with chemical personnel in all phases of the construction. The result is a modern, highly functional unit for the administration of an integrated analytical control organization in the manufacture of fine chemicals and pharmaceuticals. This description deals with the laboratory building, the large-room laboratory, the two-module laboratories and the facilities necessary for the general operation of the Chemical Control Division.

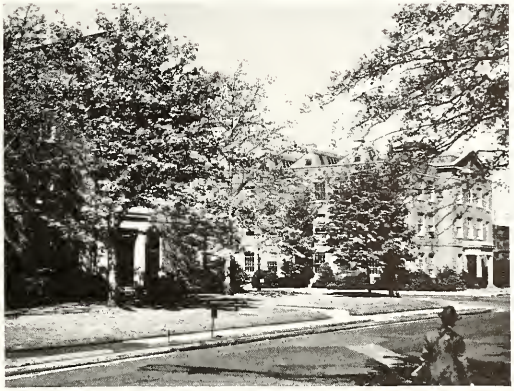


Figure III.31, Merck Institute for Therapeutic Research and the Analytical Laboratory, Merck & Co., Rahway, New Jersey.

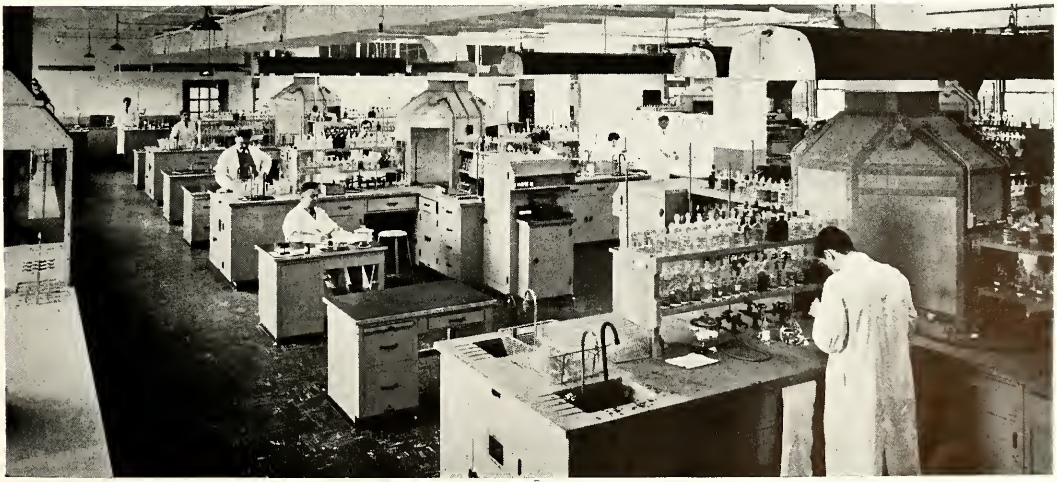
BUILDING

The analytical laboratories are housed in a three-story brick, reinforced concrete structure, 80'0" by 140'0" built to support a load of about 100 pounds/square foot (see figure III.31). Windows are conventional double-hung wood sash.

The first two floors are divided into 20-foot lanes running the length of the building. Each lane is divided into units, 20 feet square, providing the necessary number of two-module laboratories or offices.

The third floor of the building consists of a single open floor area with center colums providing truss support for the roof (see figure III.32). The roof is a

Figure III.32 Chemical Control Division. The duty of the Analytical Control Division is to see that no material of any kind gets into the factory or out of it and into use unless it meets standards of uniformity and purity. The pictured Merck cross tables are features of the main analytical laboratory. At each table four analysts can work quickly and efficiently because each unit is self-contained.



saw-tooth type clerestory consisting of a series of glass-panelled skylights which run the length of the building. The floor area provides a large-room community type laboratory. The stairways are located in the front and rear of the building, and an elevator is near the front entrance.

GENERAL UTILITIES AND FACILITIES

Lighting

Fluorescent lighting is provided throughout. An artificial light intensity of about 30 footcandles is maintained throughout the large open-floor analytical laboratory, supplemented by natural illumination admitted by the clerestory.

In the small two-module laboratory units on the first and second floors, spot illumination of 30 footcandles is maintained over work tables and apparatus. The positions of fixtures are carefully worked out to give maximum illumination and minimum shadow.

Floors

All floors are covered with dark composition asphalt tile. The particular product chosen for use in the laboratories was selected for resistance to acids and solvents. The following utilities are supplied to each work table:

Gas
Compressed air (approximately 50 psi)
Vacuum
Distilled water
Hot and cold water
AC, single-phase, 110 volts
DC (6 to 32 volts for electrolytic work, etc.)
Steam

Plumbing

All laboratory plumbing is made of bell and spigot "Duriron" pipe with joints of lead. For some extremely acid conditions, the joints have been made with sulfur cement. Drain lines are trapped at each fixture unit. All water piping is made of brass or copper. Distilled water lines are block tin. Vacuum is supplied by steam jets providing 27 inches of vacuum. Where greater vacuum is required, special pumps are used. City gas, air, vacuum, steam and hydrogen sulfide lines are made of black steel or wrought iron. High- (100 psi) and low- (30 to 40 psi) pressure steam is also piped. Hot water is developed in a standard heat exchanger. Distilled water is furnished from a still situated at a higher level than the laboratories. It operates automatically discharging by gravity from a block-tin lined storage tank through tin lines to the laboratories.

Ventilation

General ventilation is provided by the exhaust from 30 to 40 laboratory fume hoods. The air thus withdrawn is replaced by the introduction of filtered and tempered fresh air. Fresh air is distributed through metal ducts by power driven centrifugal blowers. The air replacement is at the rate of five to six complete changes per hour.

Each hood is served by an individual exhaust blower. The capacities of the blowers are designed to develop an average face velocity at the hood of 25 to 40 feet/minute. In special instances, it might be desirable to have a face velocity up to 100 feet/minute although the rate of 40 feet is satisfactory.

Fumes are carried to the blowers through ducts made of acid-resistant materials. Cast iron exhaust blowers are centrifugal, of simple paddle type construction. The capacities are from 900 to 1,200 cubic feet/minute.

Hoods

Average dimensions of hoods are 51" high by 30" deep; the front opening is 46" by 28". They are constructed of asbestos-cement board, reinforced at the seams by metal strips. Side panels, 25" by 25", are made of wire-reinforced glass. Some of the hoods in the laboratories are double the length mentioned above and have built-in steam baths and all utilities, so that large analytical apparatus requiring fume exhaustion may be set up within the hood.

Electrical Service

Electrical current is provided by having standard capacity receptacles supplying single-phase, 60-cycle AC at strategic locations on laboratory tables, within hoods and on walls. All outlets are made for accommodation of grounded three-wire connections for the protection of operators of equipment.

A small number of higher capacity receptacles are located in all walls and halls of the building for special equipment. Control panels are placed on each floor; a master panel controls the entire building. The floors are further divided into sections and areas.

Power Service

Alternating current of 440 volts, 3-phase, 60-cycle is provided from distribution panels on each floor. This power serves motors and other electrical equipment with capacities of ¼ or more hp.

Safety Equipment

To give an idea of the safety devices in use, a list of the articles placed in the large-room laboratory follows:

Fire blankets
All-purpose gas masks
Carbon dioxide fire extinguishers
Safety showers
Fire siren
Sodium bicarbonate
Safety glasses (one pair for each person)
Safety shields
Dust respirator

- Safety cans for volatile solvents
- Asbestos gloves
- Safety shoes
- Rubber gloves
- Mechanical pipetting devices
- Acid-bottle carriers

Refrigeration

Refrigeration and ice are often required in the course of routine analytical procedures. These needs are filled, for the most part, by 8-cubic-foot refrigerators placed in the large-room laboratory and in several of the smaller ones. Ice cubes of distilled water from refrigerators fill ordinary needs. Cubes are broken by a hand-cranked crusher. Larger amounts of ice are supplied by outside sources as required. Dry ice is stored in small cork-insulated cabinets and can be kept for several days.

LARGE-ROOM ANALYTICAL LABORATORY

The laboratory accommodates 24 chemists on one large floor. An examination of figure III.32 will show the arrangement of the work tables.

LABORATORY TABLES

A feature of the large-room laboratory is the design of the chemists' laboratory tables, which are in the form of a cross. Each of the four angles is designed to provide a completely equipped working area for the chemist. Each unit is a four-module installation. Six of these units are placed on the floor area, in two rows.

Each module is provided with a desk, and access to a common fume hood, located at the intersection, a sink, and a cabinet of dust-protected glassware serviced by an attendant (figure III.33). The design provides construction economy by employing common utility risers and common fume hoods for four work places. It conserves space and the energy of the personnel by reason of the compactness of the work area.

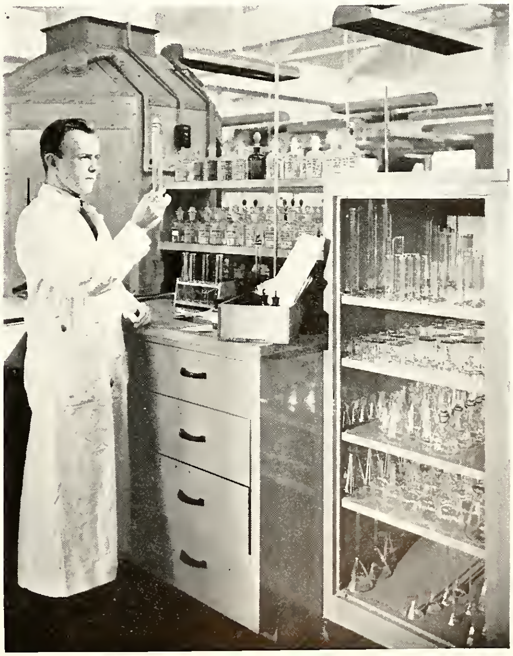
Each L-shaped laboratory table is about 38" high, 30" wide and has a linear work length of about 15 feet. It is covered with an "Alberene" stone top, 1 3/16 inches thick. Four shelves of this material are placed on the table for reagent and stock solution bottles. All laboratory furniture is enameled steel. Steel has proved to be more serviceable than wood. It requires less maintenance attention and is fireproof. Each table contains seven drawers (18" by 20" by 4"), and two double-door cabinets containing two shelves (24" by 32" by 20"). A single-door glassware cabinet containing five enameled steel shelves (24" by 14" by 54") is adjacent to each table. Shelves vary in size to accommodate cylinders, beakers, flasks, funnels, etc., of a variety of sizes.

A shallow cabinet is attached to the side of the glassware cabinet, upon which there is a torsion balance. The cabinet contains commonly used reagent materials. Two small shelves immediately above the balance are provided for each chemist's convenience in storing samples and other materials needed for weighing.

A significant addition to the work space available to the chemists is provided by a work table which runs the length of the laboratory (approximately 75 feet) on each side. The tables are "Alberene"-topped, 30" wide and 37" high. There are three hoods (51" by 30" deep, opening size 46" by 28") on each long table. The hoods are constructed of metal-reinforced "Transite" with wire-reinforced glass side panels, 25" by 25". The hoods are equipped with a six-place built-in steam bath, flush with the surface of the tabletop. Hoods are equipped with air, steam, vacuum, gas, city water and AC electricity, all controlled on a panel just below the tabletop.

Two-shelved, enameled steel cabinets, and storage spaces of about 20 cubic feet are placed alternately under the table, the length of the room. At intervals, the utilities found in the hood are provided on the table proper. Equipment, such as vacuum distilling apparatus, pH meters, a Toledo scale and other large balances, constant-temperature bath, a constant-humidity chamber containing a balance, shaking equipment, special ovens, electrolytic equipment and any elaborate analytical apparatus, is set up on these long tables for the convenience of the chemist.

Figure III.33 Chemically clean glassware is supplied in cabinets conveniently adjacent to each chemist's working area in quantities ample for his needs.



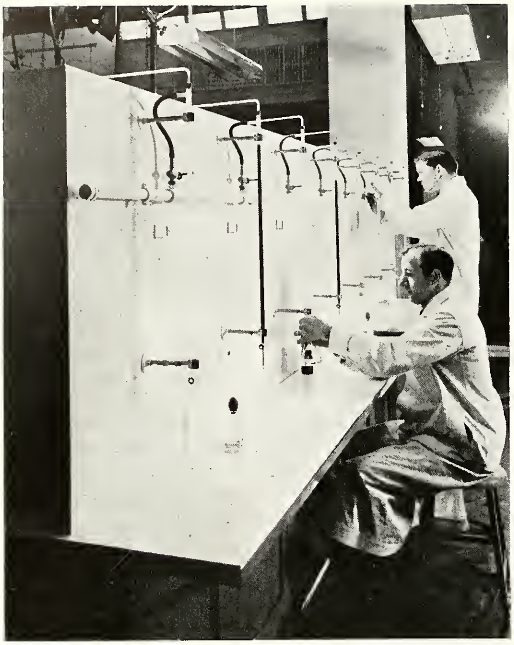


Figure III.34 Chemical Control Division. View of the titration table designed especially for the new Analytical Laboratory, showing two chemists conducting volumetric assays.

STANDARDIZED SOLUTIONS FOR VOLUMETRIC ANALYSIS—LARGE-ROOM LABORATORY

A titrating table is located in the center of the large room. Upon it are mounted burettes and automatic siphons (see figure III.34). Within the cabinet, which is of white enameled metal, are 16 carboys of standardized solutions. Eight burettes on each side of the table are individually labeled with the name of the solution, date prepared and standardized, chemist's initials, and exact strength. The ledge upon which the titrations are carried out contains dropper bottles of the necessary indicators and is covered with white opaque glass. It is 29 inches high, with stools 18 inches high placed at each burette. Daylight fluorescent illumination around the table is approximately 35 footcandles.

Balances

Twelve analytical balances are placed on fixed standard "Alberene"-topped balance tables. The tables are 30" by 30", and each accommodates two balances placed back to back. Each four-module unit is assigned to one of the balance tables located nearest to it in the center of the room.

While much can be said of the advantages of a balance room, the arrangement outlined above has proved to be advantageous and is in harmony with the scheme of providing the chemist with the facilities he needs within a few steps of his laboratory table.

One Mettler direct reading analytical balance is available for rapid routine weighing of large numbers of samples and for mass check weighings. This balance is a one-pan two-knife edge instrument which gives an automatic reading from an optical scale. It eliminates the handling of weights and is operated more rapidly than the conventional analytical balance.

Service Rooms

At the rear of the large-room laboratory are a number of service rooms which supply the chemists with clean glassware, ovens, furnaces, Kjeldahl digestors, standard sieves, automatic shaker, open storage of reagents, standard solutions, test solutions and apparatus. A large sample room for storage of reference samples is located on the second floor.

Clean glassware is supplied to the chemists' storage shelves daily. Used glassware is collected in wire baskets on each laboratory table and removed by an attendant to the glassware washing room in large rubber wheeled trucks. The glass-washing room, 12'0" by 20'0", contains a series of lead-lined sinks set into two 8-foot tables and acid-resistant alloy baskets for chemical washing all types of glass apparatus with cleaning mixture or detergent and rinsing as required. Glassware is dried in a heated-air drier, 2'0" by 3'0" by 7'0". All plumbing and fittings are of "Duriron". Two workers are constantly employed in this work. The room is enclosed with a heavy soundproof door which prevents the noise accompanying this job from reaching the ears of the chemists.

Sample Room

Space is provided for the storage of reference samples. These are filed numerically, with code numbers corresponding to chemists' reports, in a room about 20'0" by 50'0", lined from floor to ceiling with metal shelves. There are also six aisles of shelves in the room. Samples are discarded after a given period of time.

Hot Room

To provide best working conditions, a room 14'0" by 20'0", is assigned for hot equipment. The room contains a series of ovens set at the fixed temperatures ordinarily used in the analytical procedures employed. Other ovens are available for odd temperatures. The fixed-temperature ovens are efficient in saving time necessary for setting an oven at a required temperature. Nine ovens are maintained at fixed temperatures ranging from 70° C to 150° C. Fixed-temperature ovens, odd-temperature ovens, and a series of muffle furnaces are lined up on "Alberene"-topped tables, 38 inches high, on two sides of the room.

On the third side of this room is a bank of twelve Kjeldahl digestors, placed on a steel frame, 3'0" by 2'0" by 7'0". The Kjeldahl equipment consists of twelve electric hot plates, all accommodated by a common exhaust fume vent which serves to hold the neck of the Kjeldahl flasks while they are being heated. The vent is constructed of six-inch "Duriron" pipe with 12 two-inch openings to hold the flasks. The fumes are drawn off by a blower equipped with a ¼-hp motor. Fumes are trapped, neutralized and enter the general ventilation exhaust system.

A 12-foot laboratory table containing all utilities is provided for routine analytical procedures which require prolonged heating, such as continuous distillations, etc. Floor space in the hot room is utilized for storage of laboratory equipment and materials which are not affected by heat (i.e., empty bottle storage, equipment, cases of mineral acids, etc.).

Stock Room

Laboratory requirements of equipment and apparatus are filled from a stock room, 10'0" by 14'0". This room is lined from floor to ceiling with steel adjustable shelving of varying heights, but predominantly of 12-inch height. Steel cabinets are placed back to back in the center of the room leaving an aisle around the cabinet between the shelves which line the walls.

All equipment is issued from this room by one individual. With one assistant he manages this room, a general storage area, and all laboratory furniture and equipment of the control laboratory. Equipment found in the stock room is similar to that found in laboratory supply houses. Small equipment, such as stoppers, watch glasses, crucibles, weighing bottles, etc., is kept in small steel drawers wherever possible. Valuable equipment of breakable variety, such as interchangeable joint glassware is kept in its original packing boxes and is replaced in these when returned after use by chemists. Cast iron rods, stands and clamps and other bulky or heavy equipment are kept in fiber baskets on the large bottom shelves.

Continuous inventory systems are recommended for ease in ordering. The stock room attendant maintains proper stocks of equipment for efficient laboratory operation.

Physical Measurement Service

In a rear corner of the large-room laboratory, a unit with 27 linear feet of stone laboratory tables is maintained for determinations of melting points, boiling ranges, distillation ranges, arsenic determinations and other routine tests which may be performed as a service for the chemists. Fixed equipment for distillation, heating baths, etc., are maintained on laboratory tables of this unit and two technicians perform these tests and submit results to the chemists for their reports.

Whenever possible, a number of the same type of tests are issued to the technicians. This system provides efficiency and rapid service in doing routine testing of physical constants.

Reagent Rooms

The need for supplies of all the analytical reagents which might conceivably be used in the control laboratory is filled by two service rooms, each 10'0" by 12'0". The first is lined with six-inch steel shelves to accommodate open stock of solid reagents contained in 150-cubic-centimeter, or smaller, containers. A few larger containers are kept in storerooms from which to refill reagent bottles, but most reagents are generally ordered in small subdivisions. The chemists maintain a running inventory by ordering whenever a reagent bottle is half empty. Adjacent to the shelves is a torsion balance, weights and weighing supplies for rough weighings. This avoids the removal of reagent bottles from the room. An index is kept of all reagents stocked. Each reagent is given a label number to designate its shelf position so that it will be returned to the proper place.

The second reagent section is lined with larger shelves to accommodate liquid reagents and test solutions. These are prepared, labeled and dated by a trained technician. The room is fitted with a 10-foot stone-topped laboratory table and a hood used for measuring or weighing fuming materials and for preparing solutions.

These rooms contain cork-boring machines, storage of special infrequently used equipment, such as electrolytic apparatus, constant-temperature baths, etc., on large shelves, 20 inches high. Bulk reagent stocks of liquids and solids are also stored on these shelves.

Routine mesh determinations and tablet disintegration tests are performed on the laboratory table in the liquid reagent room. These tests are performed by a technician as a service to any chemist.

SMALL-ROOM LABORATORIES

A large number of smaller, two-module laboratories in the analytical laboratories of Merck & Co., Inc., are devoted to analytical research and control (see figure III.35). Work requiring specialized skill is assigned to these, as opposed to the routine testing performed in the large-room laboratory. Such duties as instrumental analysis, microanalysis, specialized vitamin or antibiotic testing are assigned to 20'0" by 20'0" rooms to which two chemists are assigned.

The layout of these laboratories is standardized, although there may be variations in any of them to accommodate specialized equipment. Most have laboratory tables 30 inches wide placed against opposite walls. A double table is placed in the center. This arrangement provides two 4-foot 6-inch work-aisles with laboratory tables on either side. The double table is divided longitudinally by a double "Alberene" stone reagent shelf. Two windows are centered with each work-aisle. Fluorescent overhead fixtures are used. A desk is placed adjacent to each wall laboratory table, with a telephone on the desk closest to the door. Laboratory tables are standard units of enam-

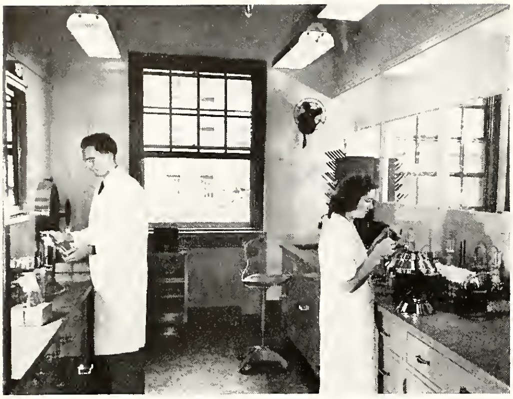


Figure III.35 Small laboratories like this dot the first floor corridors. Compact and convenient, they are ideal for specific microbial research problems.

eled steel equipment with drawers and cabinets designed to accommodate standard laboratory glassware of various types and sizes. The laboratory tables, 13 feet long, are supplied with all general utilities mentioned previously. A 5-foot hood containing steam baths, power and gas, is built into one of the wall tabletops in each room. A fire shower is positioned at the door threshold. Each laboratory contains an analytical balance which is placed on a small metal stone-topped table. Chemists have dictaphones and access to a secretarial pool for recording data conveniently.

ADMINISTRATIVE OFFICES

The front of the third floor is lined with offices and filing rooms adjacent to the large room laboratory. Wood and glass partitions separate the laboratory from the offices of the supervisory and administrative personnel. The administrators have a full view of laboratory activities through the glass panels. Seven offices for use of managers and staffs of the laboratory, quality maintenance and quality standards groups, secretarial pools for typing reports, etc., occupy this space.

For rapid communication the laboratory supervisor has a "Teletalk" public address system for two-way conversation with all parts of the laboratory and the receiving department. A pneumatic-tube system is installed for rapid delivery of papers to other buildings (e.g., receiving department, purchasing department, sales department, factory office, etc.). There are telephones in each laboratory of the building; bulletin boards are located on each floor to communicate information about rush samples to the chemists, and for other informational purposes.

The primary objective of the foregoing description is to point out the facilities required for the operation of an analytical control division in the chemical industry. Some control activities are more suited for performance in large room laboratories. A great many others are best performed in small-room laboratories. Careful examination of equipment in a variety of these small laboratories indicates that there is very little deviation of basic laboratory equipment or placement regardless of the type of activity. Planning may therefore be carried out most efficiently by designing and equipping a module or unit with all necessary furniture, facilities and utilities and then making adjustments to fit the nature of the specialized laboratory. Standardized functional units will be the result of such a procedure.

THE MICROANALYTICAL LABORATORY

This part of Chapter 3, Section 2, was written by R. N. Boos.

The purpose of the microanalytical laboratory, as here considered, is to provide the organic chemist with the results of quantitative determinations of the various elements and functional groups in organic compounds under investigation. The laboratory consists of at least two separate rooms, the balance room and the laboratory room. The size of these rooms will depend upon the number of analytical chemists employed. The accompanying diagram is a microanalytical laboratory which is of adequate size for six microanalysts. The prefix "micro" should not mislead the laboratory planner to reduction in laboratory space, hood space, sink size, etc.

When a microanalytical laboratory is to be established, it is often found necessary or expedient to utilize an existing space, and it is with this in mind that a description of the desired requirements for a balance room and laboratory room is given. If the microanalytical laboratory is to be included in the plans for a new building, the plan proposed by Alber and Harand* is to be recommended.

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* Alber, H. K. and Harand, J., Journal of the Franklin Institute, 224, 729 (1937).

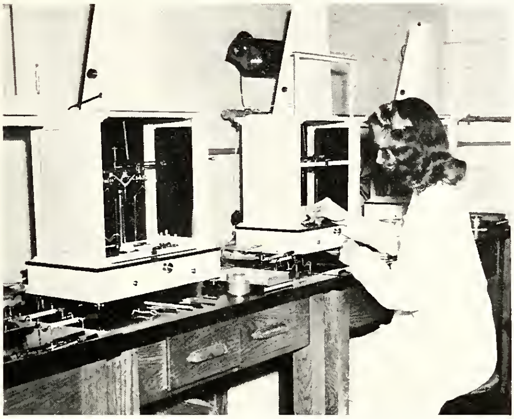

Figure III.36 Partial view of the balance room in the micro-analytical laboratory of the Research and Development Division of Merck & Company, Inc.

THE BALANCE ROOM

The ideal room in which the balances are kept is centrally situated in the laboratory for the analysts' convenience, and should not be adjacent to an outside wall of the building. Steyermark,* however, has described the necessary wall and window insulation for a balance room which is so located.

The balance room, it is generally believed, should be air conditioned, with a constant humidity of about 50%, constant temperature of 25°C, dust-free and essentially vibrationless. The humidity and temperature can be adequately controlled by any of the numerous commercially available air-conditioning units about which an air-conditioning engineer should be consulted. The dust problem may be partly solved by avoiding unnecessary air currents and by using a room which may be easily cleaned. Objectionable air currents from the air-conditioning unit may be minimized by the use of a 20-inch "Anemostat" delivering air in each (approximately) 600 cubic feet of space. There should be only one door leading to the balance room in order to prevent cross-room air currents.

The microanalytical balance is a sensitive instrument, and, besides being protected from changes in temperature and humidity, dust and air currents, it is essential that it be insulated against vibration. If the balance room is located on the first floor of a building substantially free of vibration, it is usually sufficient to have the balance placed on a solid wooden table perhaps with an "Alberene" stone top. The balance may then be supported on number 10 rubber stoppers. If, however, the balance room is located on a higher floor, or in a building not sufficiently free of vibration, it is recommended that the type of table proposed by Steyermark* be used. C. L. Ogg reports the use of individual microbalance tables (25" by 48" by 28") with heavy "Alberene" stone tops. The legs of the table rest on hard-wood blocks (4" by 4" by 2") which, in turn, are placed on ½-inch lead plates. Between the stone tabletop and the balance are cork stoppers supporting a smaller stone slab (12" by 20" by 1") on which rest the glass or plastic balance feet with hard rubber bases. It is generally conceded by most microanalytical chemists that to eliminate vibration effectively, a large number of dissimilar materials should be placed between the balance and the source of vibration. To maintain a sufficiently stable support, these materials should, of course, provide adequate rigidity.

Fluorescent lighting is recommended for use throughout the microanalytical laboratory. If optical-lever type balances are to be used in the balance room, it has been found necessary to use 18-inch or 24-inch fluorescent fixtures for each balance. These fixtures may be placed from two to three feet above each balance and the "off-on" switch should be easily accessible to the balance operator, since those lamps over the optical-lever balances may have to be extinguished before the light beam of the balance becomes visible to the operator.

The only services that have been found necessary in the balance room are electricity and vacuum.

The accompanying sketch shows the general plan of the balance room in the Research and Development Division at Merck & Co., Inc. This room is of ample proportions for six microanalysts, and it is provided with most of the desired requirements as previously suggested. The microanalytical laboratory is located on the first floor of the research building, allowing for the use of the first mentioned balance support.

THE LABORATORY

The laboratory as shown in the plan is approximately 530 square feet in area. The combustion equipment is placed near the balance room on tables 3 and 4 since the analyst using such equipment usually makes more frequent weighings than the analyst who is working on the other elementary analyses and group determinations. The services required on the combustion tables are air, gas, electricity and oxygen. A. Steyermark has found it necessary to equip his laboratory with constant voltage transformers which control the voltage to all combustion furnaces to within one volt, since the variation of the voltage in the laboratory was found to be as much as 14 volts during a 24-hour period, causing too great a temperature fluctuation of the combustion furnaces. The combustion equipment is placed on unitized steel tables (3'0" by 3'0" by 12'0") topped with "Alberene" stone. The services are located at tabletop level in the center of the table allowing combustion trains to be placed on both sides of the tables. The table is highly recommended for this purpose since it provides "leg room" for the analyst sitting at the combustion train.

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* Steyermark, A., Ind. and Eng. Chem., Anal. Ed., 17, 523 (1945).

The space beneath laboratory table 5 has been converted into one large cabinet provided with doors three feet in width. The cabinet provides a convenient storage space for permanently assembled units of equipment, such as the micro-Kjeldahl equipment, spare Dumas nitrogen equipment, etc.

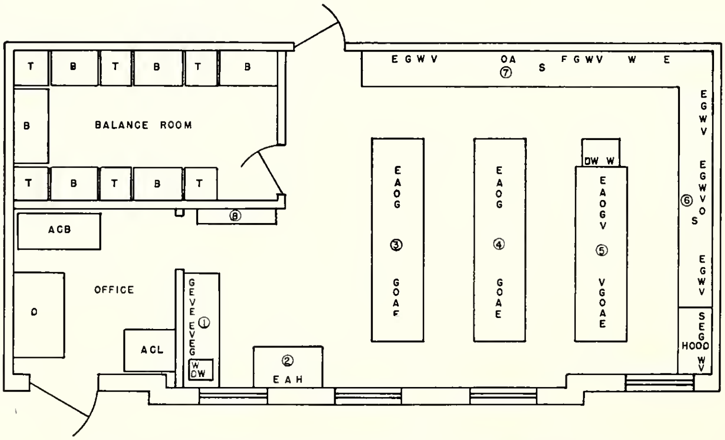
The laboratory tables 6 and 7 are of unitized steel construction, 37 inches high and 24 inches deep, provided with "Alberene" stone tops. A drain channel four inches wide and four inches deep runs the length of both tables. The services include gas, air, electricity, vacuum, oxygen, water and steam and are located above the level of the bench. Above the service lines is an "Alberene" stone shelf seven inches deep. The equipment used for the determination of functional groups in organic compounds, as well as filtration equipment, ovens, desiccators, spectrophotometer, etc., is located on these laboratory tables. A hood (4'0" by 3'0" by 3'0") provided with the same services as the laboratory table may be conveniently located at the end of table 6.

The Abderhalden driers should be located near the balance room. Table 1 is used for this purpose. It is of the same construction as tables 3 and 4 but is seven feet long and it is provided with vacuum, gas, electricity and water. The table is of sufficient length to accommodate four Abderhalden driers.

Table 2 (3'0" by 4'0" by 2'6") is used for potentiometric titrations and is provided with hydrogen, electricity and air. A storage cabinet for chemicals should be centrally located in the laboratory if possible.

The laboratory is provided with distilled water from a central tank located on the fourth floor of the building and piped in through block tin pipe. The sink drains are of "Duriron" construction. Aisles throughout the laboratory should be at least three feet wide.

The laboratory room is air conditioned by a "Yorkaire" #550 unit which is located in the office, and the conditioned air is fed into the laboratory through a 1-foot by 1-foot duct. It is independent of the air-conditioning unit which serves the balance room. Approximately the same conditions are maintained in both rooms which eliminates the necessity of a specially insulated wall for the balance room.



PLAN OF MICROANALYTICAL LABORATORY, MERCK & CO., INC.

Figure III.37.

4

METALLURGICAL LABORATORIES

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This discussion of metallurgical laboratories is based on the premise that these laboratories form a part of larger laboratories. Furthermore it is assumed that the laboratories may be engaged in the investigation of ferrous, nonferrous, precious metal or some combination thereof; but, in any event, the equipment would be used for substantially the same purposes although it might differ considerably in its detail. The exact nature of the laboratory space will, of course, be largely predicated on the equipment that is to be placed in it. Consequently the subject of equipment will be discussed in some detail to present the picture around which the laboratory frame is to be placed.

The basic equipment that such metallurgical laboratories will contain will probably be somewhat as follows: 1. metallographic equipment, 2. mechanical testing equipment, 3. melting equipment, 4. fabricating equipment, 5. heat-treating equipment, and possibly 6. coating, corrosion, welding, x-ray or other special equipment. In addition there should be adequate office and storage space.

It is assumed that general service facilities will be provided. These might include 1. clerical office, 2. conference rooms, 3. library, 4. first aid, 5. photographic facilities, 6. analytical laboratories, 7. machine shop, 8. spectrographic laboratories, etc.

GENERAL FEATURES

In any research laboratory there are certain services that are commonly needed and it is taken for granted that water, electricity, compressed air, gas, etc., are available. Ventilation, hoods and air conditioning, if needed, would also be installed as a part of the over-all building design. However, due to the specific nature of metallurgical research work, there are certain special features that must also be taken into consideration.

The handling of molten metal, of necessity, presents fire hazards. These can be minimized 1. by the use of suitable flooring such as brick or concrete, 2. by general fireproof construction, and 3. by having adequate fire-fighting devices conveniently available. The particular arrangements would, of course, have to be selected on the basis of the operation being carried out.

Concurrent with the fire hazard is a safety hazard. Handling of molten metal is dangerous and all possible provisions for safety of the personnel should be taken. These should include 1. guards around equipment, 2. convenient first-aid facilities, 3. the necessary fire-fighting devices, 4. safety clothes, 5. showers and fire blankets. Here again the exact nature of the precaution will be predicated on the type of melting operations.

There are other hazards to be encountered. If the melting or heat-treating activities are extensive, excessive heat may be developed, and this would result in inefficient work on the part of the personnel. Hence, consideration should be given to the installation of suitable fans and ventilating devices. The high temperatures may be accompanied by dirt and fumes, and the ventilating facilities should be designed to take this into account. In some instances the fumes may be poisonous or radioactive. In such a case the specific problem will require careful study to determine the necessary protective devices.

The safety hazard, of course, is not restricted to the melting equipment and all the large testing or fabricating equipment with moving parts should be protected by suitable guards. It is generally desirable to have this situation surveyed by a safety expert to be certain that all possible precautions have been taken.

In contrast to the melting operations, which at best, are likely to be quite dirty, metallographic work requires conditions which are free from dirt and fumes. If the two operations are in close proximity it may prove necessary to filter or condition the air going into the metallographic laboratories. Similarly some of the fine testing equipment needs protection and study of this situation, before the laboratory is constructed, may avoid the need for expensive changes and alteration after the buildings have been constructed and occupied.

Careful consideration should also be given to the grouping of the individual laboratories. This can do much to promote efficiency. Along with this, thought should be given to possible future expansion. It is a very common experience for a laboratory to be outgrown in a short period of time because the need for future expansion was not adequately anticipated. Modular construction lends itself well to long-range planning for expansion and, except in special cases, as in the shops, can be used to advantage in the metallurgical laboratories.

As a final general consideration, storage space for equipment, records, samples, etc. is generally found to be insufficient unless such space has been generously provided in the original design of the laboratory.

METALLOGRAPHIC EQUIPMENT

Almost every metallurgical laboratory is equipped for metallographic work. The microscope is used to identify constituents, determine structure and homogeneity, and investigate the effects of heat-treatment, determine the effects of working, corrosion, abrasion or some other specific condition. Metallographic examination takes its place along side of chemical analysis as one of the primary tools of the metallurgist and is practically indispensable in metallurgical research work.

The equipment used for metallographic work may consist of a simple microscope for visual examination, a binocular microscope, or may range up to an elaborate metallographic microscope equipped to take photographs at high magnification. In some laboratories will even be found an electron microscope, although this has not been as widely used on metals as on other materials. Larger laboratories may be equipped with several microscopes, each with its particular range and field of adaptability.

As a general rule the metallographic equipment is mounted on special benches, and with the larger microscopes provision is usually made to minimize vibration. Generally the microscopes are set up in a room or series of rooms by themselves although there is no reason why they can not be housed with other fine equipment.

In addition to the microscopes themselves, certain accessory equipment is needed. Some provision must be made for cutting off the specimens. This may be done with a hack saw, a band saw or a cutting-off wheel. With brittle materials provision can sometimes be made to nick and break the specimen while in some other special cases cutting torches are used. Whatever the method used, the facilities ought to be available as part of the metallographic facilities.

Once the specimen is cut off, it is usually mounted in some manner. Various types of clamps may be used, but probably the most common method of mounting is to cast the specimen in a plastic material. This requires a special mounting press. After the specimen is mounted it is given a preliminary facing with a file, a belt surfacer, or a grinding wheel, depending on the material being handled. The specimen is then ground on a paraffin wheel or a series of abrasive papers to prepare it for the rough polishing. This can be done in several ways so the proper equipment should be determined for the work under consideration. The final polishing is usually done on a rotating disk covered with suitable cloth and treated with a suitable fine abrasive powder. In many cases the specimens are then etched to bring out their structure, so suitable space and equipment will have to be set up to take care of this. Provision should also be made to store specimens after metallographic examination is complete, for almost invariably the specimens will be wanted for later reference. Convenient cabinets are available for storage purposes and some estimate will have to be made of the extent of necessary facilities.

In the event that the specimens are photographed in the course of the examination, it will be necessary to have a photographic dark room. This is desirable even though there are available other photographic facilities in the laboratory.

The various facilities which go to make up a metallographic laboratory are usually spaced close together for greater efficiency. However, grinding and polishing are dirty operations which release abrasive particles into the air, while etching may produce corrosive fumes. The microscope room and the photographic dark room, on the other hand, should be free of air contaminants. To overcome this difficulty forced ventilation systems, using filtered air, may be employed to allow these varying activities to be carried out in conveniently close proximity.

MECHANICAL TESTING EQUIPMENT

The mechanical testing laboratory is included here as a part of the metallurgical laboratory. The machine shop which prepares the test specimens, however, is considered a service laboratory and is not described.

There are a tremendous number of mechanical tests that may be used in metallurgical research but the ones most commonly used to evaluate metal products are the tension, hardness, notched-bar impact, torsion, and some type of bend test. However, other properties not generally used in specifications such as fatigue or creep are often investigated in research work. In this discussion therefore some attempt will be made to indicate the probability of using the tests mentioned.

Perhaps the piece of equipment most generally found in the testing laboratory is the tensile machine. The capacity and range should be selected on the basis of the anticipated use. This equipment is generally rather large and usually rests directly on the floor. Ample space should be provided around the equipment to allow for convenient operation and unhampered access to all vital parts of the equipment. In the case of the larger laboratories it will often be found necessary to have several tensile machines of different capacities and ranges, in order to handle properly all phases of the work of the laboratory.

Hardness testing equipment constitutes an important part of most testing laboratories and these tests are the simplest of all to make. Since one single hardness test is not used for all applications, the Brinell, Rockwell, Vickers, Knoop and Monotron testers are all in common use. Also there are several additional hardness tests for specific uses. Hence, it is necessary to survey the field and determine which types of testers will be required to handle the range of problems in the laboratory. In general the hardness testing equipment is not particularly large and many of the hardness testers may be installed on an ordinary laboratory bench.

Another of the very commonly measured properties of a metal is its thermal expansion. A dilatometer is therefore usually found in the metallurgical laboratory. The particular type of equipment used will be predicated on the type of work to be handled.

Fatigue machines in great variety are available to the physical tester and some of the newer machines require considerable floor space.

Impact testers are useful in the study of metals and it is desirable to be able to run Charpy and Izod impact tests. Suitable equipment may be purchased to allow running the two types of tests on one machine.

Provision should be made to allow the tensile and impact tests to be made at elevated, room or low temperatures. This requires small furnaces with their controls and low-temperature equipment, such as mechanical refrigerators, or dry ice or liquid air baths.

In addition to standard testing equipment, certain special testing equipment may prove desirable. Included might be equipment for creep testing, damping capacity, stiffness of sheet, etc. Special methods of non-destructive testing are gaining wider acceptance. These may be magnetic, supersonic, electrical, radiographic, or may involve fluorescent penetrants. Then there are a host of special tests for specific products such as wire, forgings, castings, pipe, etc. As is obvious from the above, the particular testing arrangements must be decided upon and then a suitable building supplied to house them.

MELTING FACILITIES

Most metallurgical laboratories have provisions for melting metal ranging in amount from a few grams to several tons. The type of furnace employed for such work might vary from crucible, induction furnace, arc furnace and electric resistance furnace, up to a small size open hearth or Bessemer converter. For precious metals, the melting could be done on a laboratory table while for the common metals a sizable melting shop may be employed. The latter type of shop might require an overhead crane for the handling of materials, would probably be on the ground floor, and would undoubtedly be provided with large fans to remove excess heat and fumes. The problems of design of a melt shop can therefore range from a small laboratory to those of a small industrial plant. Auxiliaries to the melt shop are an instrument and pyrometer room. A machine shop and other service facilities should be available.

HEAT-TREATING FACILITIES

The heat-treating facilities show the same possibilities for wide variation that the melting facilities do. If only a few small samples are to be heat-treated they can be handled in small furnaces and quenching tanks in a laboratory room of nominal size. On the other hand, if the quantity or size of the specimens is large, much more elaborate provisions must be made. Furthermore the exact nature of the equipment should be carefully studied before selection. The furnace may be fuel or electrically heated, or the metal may in some cases be heated directly by electrical resistance or induction. Some of the furnaces may have controlled atmospheres. Quenching baths using various quenching media such as water, oil, salt or lead should be available. In the event that the heat-treating activities are extensive adequate provisions may be required to remove excessive heat and fumes. From this it may be seen that the individual requirements for the particular laboratory will have to be carefully studied in order to design the most efficient heat-treating laboratory.

SHAPING OF METALS

Regardless of the nature of the metallurgical laboratory, there will probably have to be some provisions for shaping the metals. In its simplest form this might merely involve casting. If a wrought product is to be dealt with, the metal would probably first be cast in the form of ingots which are then forged or rolled to the necessary shapes. Such operations could well be handled in the melting shop. Other operations include machining, swaging, pressing of powdered metals, etc. The nature of the shaping equipment may vary widely depending on the particular problems of the laboratory.

Much of the equipment may be large and it may be used only occasionally. Also, the nature of the research work may shift so that additional equipment may be required. Hence, in the design of a metal shaping shop, it is imperative that adequate space be allowed for safe operation of existing equipment and for installation of new equipment with a minimum disturbance of current activities.

MISCELLANEOUS ALLIED LABORATORIES

Very often a metallurgical laboratory must take care of allied operations. These might well include coating and corrosion studies or welding investigations. Another phase of the work might involve the use of fine instruments such as the x-ray, the spectrograph, or magnetic and electronic devices. In such a case the work might well be segregated from the rest of the metallurgical work. In the event that radioactive tracers are used a whole series of special precautions would have to be taken to ensure the safety of the personnel.

Quite commonly metallurgical laboratories carry on pilot plant operations. In this discussion, however, it is assumed that pilot plant operations, when needed, are separate and distinct from the metallurgical research laboratories.

LAYOUT OF METALLURGICAL LABORATORIES

The basic pattern of what is likely to be present in metallurgical research laboratories has been discussed, and it is apparent that a competent metallurgist could design a laboratory to meet the required need. Actually, however, it is not as simple as that. Generally when a new laboratory is built the sponsors study the question of how great an expenditure can be afforded or justified for research facilities. Once the amount has been determined, it is allocated among the various laboratory functions on the basis of relative importance. As a consequence the design becomes a series of compromises directed toward getting the most effective laboratory from the available funds. Hence individual laboratories will differ greatly. However, certain basic points of similarity exist, and in discussing the layout of the laboratories an attempt will be made to present the picture of what might be designated as a typical metallurgical laboratory.

The general elements of such a laboratory would include offices, laboratories and shops. The offices have no special features except that they should properly house the personnel and allow for future expansion. In this, modular construction will probably prove desirable.

The laboratory space would be broken down into several units. The metallographic laboratory would include a microscope room, a sample preparation and polishing room and a dark room. If possible these should be adjacent, to allow most efficient operation.

The mechanical testing laboratory would undoubtedly be set up as a unit for convenience of supervision. If the testing work is extensive, the equipment might be distributed over several laboratories, but if the equipment is not too extensive, there would be advantages in grouping it in one large laboratory.

The melting shop would be expected to be quite different from the aforementioned laboratories. It would be a large shop with fireproof floors of brick or concrete. An overhead crane would be desirable for setting up or moving equipment and to take supplies to the melting furnaces. The specific need for the crane and its nature would, of course, be predicated on the extent of the operation being carried on.

The decision of whether or not to have separate heat-treating and fabrication laboratories would be largely based on the extent of such activities. If they are not extensive the work could be distributed between the shop and the mechanical testing laboratories, with the larger equipment going in the shop and the smaller and finer equipment going in the laboratory. On the other hand, if these activities are extensive, there would be distinct advantages in having separate heat-treatment and fabricating laboratories.

Insofar as the shops are concerned, it is well to keep in mind the fact that expansion of shop space may prove more difficult than expansion and rearrangement of office space. Hence it is well to plan these facilities on generous proportions, as far as the available funds allow. The problem of future expansion will then be partially solved in the initial construction.

The foregoing general remarks are designed to guide anyone contemplating the installation of metallurgical research laboratories. For the most part the remarks had to be general rather than specific, since a rather wide range of possible facilities would be included under the general heading of metallurgical research laboratories. However, it is the purpose of this outline to point out as many as possible of the considerations that should be weighed in the design of metallurgical research laboratories.

5

ANIMAL ROOMS AND EQUIPMENT

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During the past decade there has been a tremendous increase in the use of animals for toxicological assays of the effects of radiations, new synthetic organic chemicals, dusts, and other atmospheric contaminants. Federal regulations concerning food and cosmetic ingredients have stimulated long-term animal feeding and skin application studies for the purpose of evaluating chronic effects. Extensive programs for the study of cancer, poliomyelitis, tuberculosis, and other bacterial and virus diseases, coupled with studies of the therapeutic effects of antibiotics and new drugs require ever larger numbers of animals.

It seems logical, therefore, that attention should be focused upon the efficient planning of quarters to accommodate animals, particularly where in most circumstances they must occupy the same building as offices and laboratories.

The ideas and opinions proffered in this discussion are a synthesis of personal experience, and observation of what seems to have worked most efficiently in the installations that were visited.

GENERAL CONSIDERATIONS FOR ANIMAL QUARTERS

The Location of Animal Quarters

Whenever possible animal quarters should occupy the ground floor of a building. The considerations which support this view are as follows:

A. Less restriction is imposed on the physical size of species that may be used.
B. The labor required to handle incoming animals, their feed, bedding, refuse, and the necessary cages may be kept to a minimum.
C. Immediate and ready exit from the building in case of fire or the accidental escape of noxious gas or vapor is possible.
D. The installation of heavy concrete floors and the multiplicity of floor drains is accomplished more cheaply.
E. Outside runs for larger animals may be constructed to communicate with inside home cages.
F. Animal quarters may be divorced from office and laboratories, thus simplifying the air-conditioning problem.

The Size and Layout of Animal Rooms

Recommendations concerning the optimal size of animal rooms are exceedingly difficult to make unless the type of work contemplated and the species to be housed is known. In general, epidemics can be controlled better in small rooms, i.e., on the order of 500 square feet of floor space, than in rooms two or three times that size. A single unfortunate experience will convince anyone that it is too costly to house extremely large numbers of animals in one room. It is also good practice to house a single species in a room.

Personal experience has shown that for maximum efficiency, where work is divided so that two persons constitute a team doing standardized tests on a single species of small animal, a combined housing and treatment room is preferable. This eliminates trucking animals from one room to another and allows weighing, identification, treatment, and observation to be done with a minimum of waste motion. Maintenance of the colony is generally allotted to a third person who works on a definite schedule to avoid interference. With this principle in mind the room should be planned to house the maximum number of animals required to keep the specified personnel fully occupied. Auxiliary isolation rooms could be maintained if the turnover of animals is great, or if any extended period of preliminary observation of the animals is required.

For most efficient and convenient use the size of the racks or cages to be installed should be decided upon in advance of the actual planning of room sizes, so that space will not be wasted unnecessarily in wide aisles. For rats and mice, single cage racks along the sidewalls and two rows of double cage racks running parallel to them through the center of the room is favored. This requires three aisles not less than 4 feet in width. The minimum room width required with this distribution of racks would be about 20 feet. The length of the room would be governed by the number of units that are to be placed end to end, plus an allowance for at least 3 feet of aisle space at each end and adequate space for utilizing the end walls. A suitable sink and a work shelf 2 feet wide might occupy one end of the room and 12- or 18-inch steel shelving might be placed along the opposite end-wall next to a doorway. If three standard racks are placed end to end lengthwise, then the over-all room length would be about 25 feet. Such a plan would comfortably house six single and six double cage racks with a minimum capacity of 1800 rats or twice that number of mice. For chronic feeding studies an installation such as this would be large enough to keep two persons fully occupied.

Many animal rooms in current use are much larger than that recommended and no doubt special problems justify their use. However, other things being equal, the relatively small room approaching a square in dimensions provides the maximum floor area and the most convenient working space for handling small animals.

Layout. An orderly arrangement of rooms to limit the traffic through them is requisite. Food and bedding storage should be centrally located. Breeding rooms should be kept away from noisy areas. Rooms for weaned stock should be adjacent to the breeding rooms. If separate dosing or preparation rooms are planned they should be adjacent to the room in which the species to be used is housed.

Animal Room Interior Finishing

Floors. Of the numerous floor surfacing materials on the market, one preparation in particular has incorporated in it many desirable features for animal rooms. This material is a cupric oxychloride cement* which inhibits the growth of bacteria and molds to a remarkable degree over an extended period of time.† Finely powdered copper is added to the cement base and during and for long periods following the initial hardening, the metal powder reacts to form a new phase in the cement composition which has been identified as cupric oxychloride. In addition to its direct inhibition of putrefactive microorganisms, controlled laboratory tests have demonstrated that it is roach repellent.‡ In other words, if one room is finished with this preparation in an infested building, roaches will avoid the treated area. No claim is made that this flooring is lethal to these insects but, where it is present, they will seek areas not so treated. It may be laid over new or old concrete or wood floors, and there is no good reason why it should not be a satisfactory installation over floors that contain radiant heating elements. The maker advises that the preparation should not be heated above 160°F, but it is unlikely that such a temperature would ever be needed to heat an animal room. A surface coating ⅜ inch in thickness is recommended for use on floors. Furthermore, there is no obvious objection to the use of this cement on the lower portion of the walls of animal rooms, if the color and light reflection values are satisfactory. If this material is properly applied cracks and crevices should not develop. The user may specify the surface finish to be applied so that the hazard of a slippery floor may be reduced.

Floors that are to be equipped with built in drains should be sloped to such an extent that water will not be retained on any portion thereof. Particular care should be exercised in this connection to avoid greater pitch than is absolutely necessary, otherwise inconvenience and unsightliness may result if mobile cage racks are to be used in the room.

Tile floors of many varieties have been used where floors are to be flooded for cleaning purposes. A word of caution in this connection might be apropos. If animal rooms are situated on other than the ground floor, expensive corrective measures may be necessary if the tiles become loosened to such an extent that water can seep between them to the rooms below.

Baseboards. Baseboards should be of cove type for ease in cleaning, and in most cases it will be found that they can be an integral part of the flooring. Great care should be taken to make a crackproof seal where they join the wall. It is preferable to have them taper to the wall so that no ledges are left where dirt or moisture can accumulate. If tiled floors and walls are used, a specially shaped tile will be furnished to accomplish the transition from floor to wall.

Walls. There is little to criticize in a plastered wall, provided a hard finish coat is applied; a good high-gloss paint will withstand repeated washing.

Glazed tile, carefully laid, makes a very attractive wall but is quite expensive. Some saving may be achieved by carrying the tile about two-thirds of the distance to the ceiling, or to a height of about 6 feet, and finishing the remaining portion of the wall and ceiling with hard smooth plaster. If the windows are located above the 6 foot level, further installation costs may be effected. One objection that may be raised against tile is its fragility. If it is subjected to a hard blow it may break and leave a sharp ragged edge which creates an accident hazard. Furthermore, if the walls beneath are of hollow construction, they immediately become accessible to vermin.

A comparatively new treatment is the use of a plastic coated wall covering which may be procured in 4-foot widths. This can be applied with a suitable adhesive to a height of about 6 feet over a plastered wall. Butt joints are used which leave no visible openings between the sheets. The walls above this covering may be skim coated with plaster to make a continuous smooth wall. This material is scuff resistant to a remarkable degree and will withstand cleansing with many different solvents. It may be washed with water repeatedly, without damage, and it is available in a wide variety of colors.

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* Sold under the trademark name "Hubbellite" by the H. H. Robertson Co., Pittsburgh, Pa.

† Farrell, M. A. and Wolff, R. T. Effect of Cupric Oxychloride Cement on Microorganisms. Ind. Eng. Chem. 33, 1185, Sept. 1941, and Mallmann, W. L., A. Bacteriologic Study of a New Sanogenic Flooring. J. Am. Med. Assoc. 117, 844-847, Sept. 6, 1941.

‡ Hazard, F. O., Roach Repellent Cement, Soap and Sanitary Chemicals, April, 1945.

If wall board of any type is used it is mandatory that all crevices be sealed with a suitable filler, or a tight fitting metal molding be used to cover the joints.

Doors. Doors should be sealed with metal if frequent spraying or washing of the room is to be carried out. Door knobs are troublesome as they always manage to be in the way of passing trucks. Push plates of metal may be used on the inside and curved pulls may be fastened at elbow height on the outside. Door stops which swing up when not in use and release to hold the door open are necessary when positive action door closures are used. Doors operated through the control of photoelectric mechanisms may be desirable in locations where there is inordinately heavy traffic. Locks with manual control on the inside and opening only with a key from the outside are satisfactory. All fittings must be tightly installed or gasketed so no penetrable crevices exist. Door transoms are not advocated; they furnish a refuge for vermin and a lodging place for dust.

Windows. In air-conditioned rooms a sealed window or glass brick may be used. Animal room windows should be located above a height of 6 feet so that maximum usable wall space can be preserved. Cold windows will chill animals if the cages are situated adjacent to them even if room temperature is optimal. Trouble was encountered in some early glass brick installations with separators that did not compensate for expansion and contraction with seasonal temperature changes. Particular attention should be paid to the composition of the sealer in which the bricks are laid.

Window ledges should be beveled so that no horizontal areas are available to collect dust and dirt. When openable windows are used, provision should be made to prevent direct drafts on the animals.

Ceilings. Hard, smooth plastered ceilings coated with gloss paint are satisfactory. Openings around fixtures or pipes should be sealed to prevent entry of vermin.

Lighting, Heating, Plumbing, and Air Conditioning

Lighting. Recessed open troffer fluorescent ceiling lights equipped with daylight and white tubes produce good illumination. Vertical diffusers which may be demounted quickly for ease in cleaning are desirable. Glass covers should not be installed as that will provide a warm, comfortable housing and breeding place for vermin unless they are tightly sealed.

When feasible, lights should be controlled from switches located in the corridor outside of the room. This procedure would eliminate reaching behind cage racks to find the switch and the possibility of water entering the switches when the animal rooms are washed. However, if they must be placed inside the animal room, each switch should be sealed with a gasket so that vermin cannot get behind it.

Wall electrical outlets should be located sufficiently high so that they will not be subjected to a direct stream of water from a hose when floors are washed. The waterproof capped type outlet should be demanded and should likewise be gasketed.

Both single-phase 110-volt and three-phase 220-volt lines should be installed in any new laboratory to take care of the various current needs.

Heating. Although no first hand information upon the successful use of radiant heating can be cited it would seem desirable to heat animal rooms with elements located in floors, baseboards, or walls as seems most economical or convenient. Aside from the even heat distribution achieved, the room would undoubtedly dry much more rapidly after washing.

Plumbing. Animal room floors should be provided with non-clog bucket-type drains to allow for rapid washing. It would be best to modify the drain covers by the elimination of the openings in the cap plate. This recommendation is made to eliminate the possibility of the drain becoming a housing place for roaches. When the drain is to be used the cap plate can be removed and all debris will be collected in the removable bucket. Lime is usually placed on the floor of the bucket to discourage invading vermin and to prevent odor formation.

A sink is a necessity in any animal room whether or not the cage washing is done there. The most durable units are made of "Alberene" stone supported by ordinary pipe and pipe flanges. Angle iron may be used for load bearing spans. All crevices between angle iron and "Alberene" and between the sink and the wall should be sealed with a waterproof nonshrinking putty. The sink drain should have a strainer in the tailpiece to prevent debris from accumulating in the trap. Drain pipes 1½ inches in diameter will usually give trouble-free performance. The conventional mercury trap, consisting of concentric grooves cut into the sink floor around the drain will prevent a considerable amount of debris from entering.

Loose peg sink-boards for draining glassware, should be avoided as they usually serve as multiple roach breeding compartments. Open grille shelves over the drainboard will serve as a good substitute.

A dependable continuous supply of hot water is a necessity. Cold water may be piped to cage racks that are permanently installed if it seems desirable to introduce the system of keeping the same water bottle on a given cage to prevent the spread of infections. This method will not be found practical if movable cage racks are used. The installation of restaurant-type glass fillers on water lines affixed to the cage racks will speed up the water bottle refilling operation or, as an alternative, the automatic type fount valves may be used. Animal breeding rooms, and rooms devoted to life-time feeding studies should be thus equipped.

Air Conditioning. Personal experience with rats on 2-year feeding experiments in rooms without air conditioning, when compared to the experience of other workers using air-conditioned quarters, has offered convincing evidence of its necessity. The mortality from lung infections alone, with no air conditioning, may run as high as 30% by the time rats are 1 year of age. Mortality statistics furnished by laboratories doing similar work in air-conditioned quarters reveal mortalities of only 10% to 15%. Rodents are particularly susceptible to high temperatures which are prevalent in the north temperate zone during the summer months. Air conditioning their quarters seems to be the only method of correcting the situation.

Lest the uninitiated in such matters fall into trouble by being too sketchy in their recommendations to the contractor let it be said that if year around temperature and humidity control are desired this point must be emphasized. The usual package unit that is installed in a room will reduce the temperature and the humidity; but unless auxiliary equipment and automatic controls are provided it will neither humidify nor heat air to compensate for inadequate moisture and heat. Therefore, if it becomes desirable to recirculate animal room air and supply only a fractional portion of fresh air, it will be impossible to control humidity and temperature in the winter months without auxiliary heating and humidifying apparatus. The difficulties described pertain where one or two rooms are to be air conditioned, not to new complete air-conditioning systems.

Animal room odors, which are intensified by increasing the relative humidity, may be controlled by the use of activated carbon filters built into the ductwork of the air-conditioning system. Recent investigation has shown that air passed through a 12-inch bed of 10- to 24-mesh activated carbon is freed completely of bacteria, as well as yeast and mold spores. Consequently, if it develops that beds of lesser depth work efficiently in this respect, the addition of activated carbon filtration to air-conditioning equipment will serve to sterilize and deodorize the air.

The installation of ultraviolet lamps, or the use of aerosols to reduce the number of air borne microorganisms is not considered essential for rooms in which small animals are housed. Small animals do not propel droplets containing bacteria into the air by vocalizing, coughing, and sneezing as do larger animals. The usual respiratory infections are found distributed sporadically in rodent colonies and they do not spread from cage to cage in a linear fashion. Experience would indicate that direct contact is responsible for the spread of such infections. One infected animal in a cage usually infects the others so that all occupants of a single cage are lost. In our opinion, designating one water bottle and one food container to be used with a given cage and on no other, and sterilization of cages after cleaning will do more to prevent the spread of infection than attempting to sterilize the air.

When large numbers of monkeys or dogs are to be kept together there would seem to be better reason for air sterilization, but personal experience has never been of the sort to justify even this recommendation. The penetrating power of ultraviolet light is low and its lethal effect on microorganisms is inversely proportional to their distance from the tube. Some ozone is generated from the tubes which may furnish a concentration in excess of the 1 part per million which is the recognized hygienic standard, or upper permissable limit for constant exposure of humans.

In contrast to the opinion offered above, a recent report on the use of glycol vaporizers in a mouse breeding colony showed a 50% reduction in respiratory infections. The normal mortality without glycol vapor was 10.95% of 550,000 mice and only 5.4% of over 600,000 mice after the installation of glycol vapor. These figures are based on yearly production. This same breeder lost 18.9% of 640,000 mice during a year when respiratory infection was rampant, and he is of the opinion that glycol vapor would have reduced spread of this epidemic had it been in operation.

SPECIAL FACILITIES

Radiobiochemical Laboratories

The general construction of quarters and suggestions for the care and housing of radioactive animals are discussed by Norris.* He suggests a separate room provided with smooth decontaminable surfaces and equipped with a modified stainless steel hood in which the actual dosing of animals should be carried out. This hood should be designed to provide simultaneous access on at least two sides and it should allow the workers to maintain glass surfaces between the operations and the exposed portions of the body, particularly the face, at all times. This room should be as close as possible to the area which will be used to house the radioactive animals.

Quarters for radioactive animals should be made of smooth decontaminable surfaces like the laboratories. The entire room should be water-tight and equipped with low-pressure steam and hot water connections for washing purposes. Each room should have a floor drain, and, if the activity levels are high enough, the drain pipes should be connected to a hot drain.

Cages for animals should be constructed of stainless steel as it withstands cleaning and decontamination more effectively than other metals. Tanks for immersing cages in appropriate decontaminating solutions are needed if numerous cages are used. This treatment may be followed by application of hot water and steam for further decontamination and sterilization.

It is obvious from the above summary that the whole problem of radiochemistry should be studied before an attempt is made to design quarters for housing contaminated animals. The radiochemistry laboratory symposium, published in detail in the February 1949 issue of *Industrial and Engineering Chemistry*, is a fertile source of such information.

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* Norris, W. P., Ind. Eng. Chem., 41, 2, 1949.

Infectious Disease Laboratories. The problem of housing animals infected with pathogenic organisms or viruses causes major concern to the director of such laboratories. The escape of animals or faulty technique on the part of one person may endanger the lives of others. To reduce the extent of the hazard one research institute has planned the construction of a one-story T-shaped building, with each leg of the T divided longitudinally by a solid wall. This will provide 6 identical separate infectious disease laboratories each of which will have its own separate entrance.

Admittance will be restricted to persons actually engaged in the work carried out in the building. Street clothes will be left in lockers adjacent to the entry, a shower will be taken, and work clothing kept in lockers on the other side of the shower will be donned. When leaving work the procedure will be reversed.

All incoming feed, bedding and equipment may be sterilized if necessary in a unit provided at the junction of the arms of the T. This area will contain an incinerator capable of ashing all refuse, infected animals, etc. from the laboratories. Such an installation is an example of the current trend to segregate infectious disease studies from other laboratory procedures.

Diet Kitchens. Laboratories engaged in nutritional studies find it expedient to equip a separate room with facilities for the preparation of special diets. It is beyond the scope of this discussion to recommend the best type of equipment or layout for such installations, but attention should be called to the use of separate booths for weighing the ingredients of a given diet when several are to be prepared over long periods of time. This idea may serve to prevent costly mistakes.

Storage Rooms. Usually after plans for a building have been made, the space allocated to storage is purloined to fill last minute requests for space or to take care of oversights. Adjacent to animal quarters it is absolutely essential to have vermin-proof food storage facilities, and adequate space to store the sawdust, peat moss, paper or whatever is used to collect animal excreta. Another closet or small room should be provided for cleaning equipment, disinfectants and the like. A room for the storage of cages and racks temporarily not in use should not be considered a luxury.

In large installations where an incinerator may not be available, a room may be used for the daily accumulation of refuse. Such rooms should communicate by means of a loading chute to the outside, so that the refuse may be loaded directly into the vehicle used for its removal.

A cold storage vault or a restaurant-type storage refrigerator should be provided for holding an adequate supply of perishable foods that are often fed as adjuncts to the commercially available dry diets. For the small animal colony the conventional household refrigerator will suffice.

Fire Control and Auxiliary Safety Devices

Fire Control. Sprinkler systems which operate when a certain temperature is exceeded have been installed in one recently built laboratory housing animals. It would seem reasonable to have CO_2 or other recommended types of extinguishers available in all large rooms so that incipient conflagrations could be halted. An alternative would be to install extinguishers at intervals along a common corridor if such is provided.

If corrosive chemicals are to be handled in and about animal rooms, chain-operated emergency showers which deluge the whole body with 30 to 40 gallons of water/minute should be installed. An eye-washing fountain operated by the pressure of the forehead on a control button which opens water jets directed to flush both eyes simultaneously is also essential. This type leaves both hands free to hold the eyes open.

CAGE EQUIPMENT

Large Animals

For the occasional use of animals such as horses, cattle, sheep, goats and pigs, a room on the first floor provided with a ramp for ease of access is usually planned. When large numbers of a given species are to be housed, special buildings must be provided and these are not included in the scope of this discussion.

For small laboratories concrete curbs may be installed to serve as an anchorage for pipe railing of sufficient strength and height to confine the various species of animals. Floor drains are installed in gently sloping floors so that each compartment can be individually washed. Four pens can be built conveniently in an area of about 16'0" by 28'0" leaving a 4-foot center aisle between the pens which will measure about 6'0" by 14'0".

Dogs and Monkeys

Separate rooms devoted to a single species are in vogue for animals of this size. If ground floor or penthouse type quarters on the top floor are utilized, exercise runs can be provided. Cage fabricators furnish standard wire panels in various sizes which can be assembled to provide adequate runs. Sliding doors communicating with these outside runs are installed so that in good weather the animals may have free access to the exterior. A canopy for protection against strong sunlight and rain is built over that part of the run adjacent to the building for dogs, or a wire enforced glass roof may be constructed over runs for monkeys. With ground floor installations, shrubs planted around the runways will serve to conceal them from the passersby.

If built-in cages are to be used, floors are sloped to a trough outside and in front of the cages which in turn feeds into a floor drain. This permits daily flushing of the cages and eliminates the need for an absorbent bedding. Stainless steel watering and feeding pans will prove to be a good investment from the point of view of longer life and ease in cleansing. In planning such installations, it may be worth while to arrange the separating wire so that animals in adjoining cages cannot contact each other. Expanded metal cages should always be fabricated with the long axis of the diamond on the horizontal so that animals will not damage their legs if on occasion they extend them through the openings. The same standards of comfort and cleanliness which are followed in the planning of facilities for the modern animal hospitals should be applied to the design of laboratory quarters for dogs and monkeys.

Cage suppliers build all-metal units that will serve for both metabolism studies and housing. These cages may be stacked one on top of the other to provide a double tier of cages if desired, but maintenance is much more difficult than with the built-in variety. In monkey rooms the common practice is to provide a false ceiling of standard wire panel over the cages so that when monkeys escape they can be caught readily. All accessible windows should be screened on the inside with wire, as these animals may not fully appreciate that glass is supposedly a barrier to their flight. Building a double-door maze for the entrance to monkey quarters is the best insurance against their escape.

Small Animals

Mice, rats, hamsters, guinea pigs, ferrets, rabbits and cats may be housed in metal cages which are procurable from suppliers listed below.* In selecting cages it is well to keep in mind that if they are to be washed repeatedly and used continuously, stainless steel or "Monel" metal may be more economical over a period of years than galvanized cages. The selection of one type of cage for a given species is desirable so that all are interchangeable. Cage spaces should be numbered on the cage racks; not the cages themselves. This will avoid confusion when cages are to be washed as animals can be transferred to clean cages from any rack while their fouled cages are being cleaned. If a number of cages are to be removed simultaneously a clip-on button with rack space number may be temporarily affixed to the cage.

Cleaning and sterilization of cages, rearrangement of equipment and operating convenience are best served by movable cage racks mounted on casters. As a preventive measure against crawling insects gaining access to the cages, a metal cup designed to hold oil or liquid poison may be welded around each leg of the cage rack several inches above the caster.

Cages and racks should be selected or designed so that no cracks or crevices exist to serve as a lodging place for feces and the collection of urine. The completely welded cage is far superior in this respect to the folded joints of sheet metal and wire mesh that are also available. The wire mesh for the floor should be of sufficient size to allow the unobstructed passage of formed feces.

Small animal cages of the open top variety suspended on slides are time savers in that animals do not have to be removed nor doors opened for routine cleaning of droppings. Thirty-pound-weight waxed Kraft paper may be used in place of pans for the collection of excrement. This paper is fed from rolls attached to the cage racks and cleaning is accomplished by pulling out the soiled portion. A beveled or cove corner in the cage rack shelf will prevent excreta from getting under the edge of the paper.

Guinea pigs and hamsters may be housed in cages designed primarily for rats and mice. Available also are general purpose cages which will serve for guinea pigs, hamsters, small rabbits and cats. Cages of this type would serve best in small laboratories where a few animals of each of several species are to be housed. In general these have door fronts, removable wire floors to support the animals and pull-out dropping pans.

The housing of large numbers of rabbits in the laboratory calls for considerable floor space if the usual three- or four-tier rack is used. Capacity may be increased by having racks fabricated six or more tiers in height, but this is done at the expense of ease in maintenance. The primary consideration is in the selection of a convenient, easily cleaned, sturdy, well-constructed cage, with feed and water devices attached on the outside so that cages will not have to be opened several times a day.

Frogs

The maintenance requirements of the common species of frogs are similar. Temperature conditions are most important as frogs survive best at 18° to 20°C. At this level they feed well and do not hibernate. In the laboratory, if their diet is deficient, frogs which become dormant do not recover completely and the mortality after emergence from hibernation is high. As frogs enter the stuporous state at a temperature slightly under 10°C, this is the lowest temperature to which they should be subjected unless dormancy is desired.

For short-term holding of a week's duration frogs may be stored at 8°C. This will produce dormancy and they should be used up rapidly after they revive. For 30-day studies the frogs should be kept in individual cages on a shallow bed of moist peat moss arranged to slope so that moisture will drain to one end leaving the upper end dry. This will allow the frog to select optimal moisture conditions. In no case should standing, open water be used in the cage. Zinc, copper, lead and brass and the like are toxic to frogs and therefore stainless steel wire, or perhaps plastic screening, should be used for cages. Chlorine treated water is also irritating and should be avoided or treated to remove chlorine before use.

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* The following list contains the names of dealers known to the writer who are currently manufacturing animal cages and equipment, and it is not presented as being either selective or comprehensive:

American Lincoln Incubator Co., 645 Somerset St.,
  New Brunswick, N. J.
Baltimore Wire & Iron Works, 510-512 No. Jasper, Baltimore, Md.
Biedling & Olberg: Metal Works, 10th and Chestnut St., Chester, Pa.
Buffalo Wire Works Co., Inc., 499 Terrace, Buffalo, N. Y.
Bussey Products Co., 6000 W. 51st St., Chicago 38, Ill.
Ford Fence Co., 6567 Cornell Ave., Indianapolis, Ind.
General Biological Supply, 761-763 E. 69th Place, Chicago, Ill.
Hartford Metal Products, Inc., 48 Gayley, Aberdeen, Md.
Hoeltge Bros., Inc., 1919 Gest St., Cincinnati 4, Ohio
Norwich Wire Works, Inc., Norwich, N. Y.
Shenandoah Equipment Co., Harrisburg, Va.
Wahmann, Geo. H., Mfg. Co., 1123 E. Baltimore St., Baltimore, Md.
Western Wire & Iron Works, Inc., 950 W. 19th Place, Chicago, Ill.

Where large numbers of frogs are used routinely, an icebox with cooling coils behind baffles, may be used to store frogs in the dormant state. These boxes are equipped with an open drain in the bottom which furnishes a port for sufficient ingress of air, and daily opening and closing of the doors allows for further air changes. Frogs are stored in groups in open trays in this box. Before they are to be used they are transferred to a conditioning tank and into individual cages made of stainless steel sheet and wire. The temperature of this cooler, on the order of the soft drink cooler, is kept at 18° or 20° C. Dosed frogs are returned to this cooler for holding until final observations are made. If extended studies are carried out other provisions must be made so that they can feed freely, or individual hand feeding must be relied upon.

The frog is particularly susceptible to a disease known as red leg, characterized by red spots which develop on the hind legs, and particularly on the under side of the thighs. This infection is caused by *Proteus hydrophilus*, and warm, stagnant, dirty water affords the ideal condition for the infection to arise and progress.

Insects

The rearing of insects is a specialized procedure and rigid specifications are set up for breeding and housing insects to be used for insecticide testing. One of these is the Peet Grady method[*] or the official method of the National Association of Insecticide and Disinfectant Manufacturers for evaluating liquid household insecticides. This method requires that the rearing room for house flies be maintained at 82±2°F and relative humidity of 50±5% and indicates that 1 cubic inch of space per fly is required for caging.

Roaches may be raised under the same temperature and humidity conditions as flies. Rearing chambers[†] may be 24" by 16" by 8" of stainless steel #4 finish, finished side inside, corners filled with solder and polished to present a smooth surface. A cover of 16-mesh copper screen is used. To increase floor area, platforms of ⅛-inch "Masonite" 7½ inches in diameter with a ⅝-inch center hole and ½-inch legs cut from 1-inch doweling are stacked on a central rod of ½-inch doweling. Three or four series of these six-level platforms are used per chamber. Water is served in a pint-size cadmium plated chicken waterer. The chamber floor is covered with a ½-inch layer of coarse sawdust and upper walls are greased with vaseline mineral oil mixture to prevent escape.

For rearing Drosophila, reference is made to the "Drosophila Information Service" edited by the Dept. of Genetics, Carnegie Institution, Cold Spring Harbor, New York. This publication, together with "Culture Methods for Invertebrate Animals",[‡] will provide adequate information for anyone anticipating the use of this species. For additional information on insect rearing and equipment see the references below.[**]

Cage Washing and Sterilizing

In most large laboratories housing animals, provision is made for a separate room or rooms for cage washing and sterilization. Either a large steam-heated soaking tank or a steam sterilization booth which will accept an entire rack of cages is utilized. In either case, hand scrubbing of cages will be necessary to insure clean cages, but the work is appreciably reduced if the cages are pre-soaked, or sterilized in flowing steam.

If a tank is installed it will be necessary to provide a chain hoist to lift dog or monkey cages in and out of the tank. Numerous small cages can be loaded into such a tank and a large amount of hand scrubbing eliminated if they are held for ten to fifteen minutes in water at 80° to 90°C. Such an installation will be adequate for laboratories not handling animals infected with pathogens.

Steam sterilization is advocated for equipment used to house infected animals. An exposure period of one hour or more is necessary to kill most species of bacteria; but when the resistance of a given pathogen is known the time should be reduced or extended as is required to effect sterilization. Stainless steel lining for the sterilization chamber is recommended, as many materials will not withstand the continuous exposure to heat and moisture and soon become unsightly and useless.

Large soapstone sinks seem to wear best under conditions of continuous use where small cages are to be hand scrubbed. Mixing spigots with hose bibs are requisite and the drain pipes should be large so that fecal material will readily pass into the sewer. Fabricators of bottle washing machinery no doubt could build a successful cage washing machine, if the number of cages involved justified such an expenditure of funds.

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[*] Blue Book 1948, 20th ed., pp. 183-186. MacNair-Dorland Co., 254 West 31st St., New York, N. Y.

[†] As used by the Insecticide Division, Gulf Research and Development Company.

[‡] Galtsoff, P. S., Lutz, F. E., Welch, P. S., and Needham, J. G., Culture Methods for Invertebrate Animals, Comstock Pub. Co., Inc., 1937, Ithaca, N. Y.

[**] Hartzell, A., Haynes, H. L., and Connola, D. P., Apparatus Used in Laboratory Insecticide Tests at Boyce-Thompson Institute, Contrib. Boyce-Thompson Inst. 15 (3):131-140—April-June, 1948; Granett, P. and Haynes, H. L., Improved Methods of Rearing Aedes Aegypti Mosquitos for Use in Repellent Studies, Proceedings of 31st Annual Meeting of the New Jersey Mosquito Extermination Ass'n. held at Atlantic City, N. J., March 15, 16, and 17, 1944; Sacktor, B., Hutchinson, M. and Granett, P., Biology of the Lone Star Tick in the Laboratory, Journal of Economic Entomology 41: (2): 296; Peterson, A., A Manual of Entomological Equipment and Methods, Ohio State, 1934, Edwards Bros., Inc., Ann Arbor, Michigan.

6

INDUSTRIAL LABORATORIES FOR PHYSICAL MEASUREMENTS

Harold P. Klug

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Physical measurement laboratories comprise laboratories for physical chemistry, general physics and a host of more specialized techniques such as: x-ray diffraction, electron diffraction, electron microscopy, the various branches of optical spectroscopy, mass spectrometry, physical testing and others.* In addition, there are certain other specialized devices for physical measurements such as cyclotrons, wind tunnels, atomic piles, etc., which require, generally, a very special building, and which obviously are outside the province of the present volume.

At the outset it will be well to remind the reader that the term laboratory has a conventional connotation to most individuals. It is thought of as a place where specialized equipment is permanently and perhaps rigidly located, and to which specimens are brought for measurement and study. In some industrial problems, however, the problem is not mobile. A considerable amount of industrial radiography and physical testing is of this type. The laboratory must then be considered from its most basic aspect, that of working space. The fundamental requirement is that the space, facilities and equipment be flexible enough to permit the most adequate investigation of the problem. It is often necessary to build a prototype or scaled model on which tests must be made as it is assembled, and to which test facilities must be brought. Obviously, the planning of such *unconventional* laboratory space must be integrated with the planning of the laboratory building as a whole. Actually, the entire Bell Telephone Laboratories, Murray Hill, New Jersey, embodies this feature of flexible space and facilities. It is, of course, a simple matter to fashion the conventional laboratory from such space.†

The problems arising in the design of laboratories for industrial use are related to, but not the same as, those for instructional use in colleges or universities. An industry in setting up a physical chemistry laboratory for control may require many measurements in only one or two fields—viscosity, surface tension, refractive index, etc., whereas a university teaching laboratory may need to provide in the one laboratory facilities for teaching most of the common techniques of physical chemistry or physics. The facilities and layout will thus take into account the industry's special requirements in the field of physical measurements.

Frequently, a great deal of thought will have been given to the general plan of construction for a new laboratory building before the design of the individual laboratories is considered. A word of caution should be spoken against such a practice, since physical measurement laboratories, in particular, have certain special requirements which may have an important bearing on the general construction. Modern laboratory planning favors the module idea in construction. Actually, there appears to be almost no technique of physical measurement that does not lend itself to the module plan. It might almost be said that modular construction is a necessity for the most practical and workable layouts in these laboratories, since the specialized techniques usually require rooms of different sizes which are readily achieved under the modular plan.† Suggested layouts for certain techniques, based on an average size module, are included later in the chapter.

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* Constant-temperature-humidity rooms, and laboratories for metallography, electrochemistry, radiochemistry, and high pressure studies are discussed in individual chapters elsewhere in this volume.

† See, "Partition Flexibility at Murray Hill," J. G. Motley, Bell Lab. Rec., 21 6-14 (1942).

The problem of the distribution of power in the building may depend to a considerable extent on the demands and special requirements of the physical measurements laboratories. The decision to air condition may be related to the special needs of some of these laboratories. The necessity for avoiding vibrations in the finished structure must be considered early in the planning. In physical testing the desirability of planning so that service lines will be as short as possible, that heat may be removed from the laboratories, and that heavy equipment may be moved in and assembled should be noted. Finally, it is most important that the laboratories be arranged so as to permit easy cleaning and maintenance.

It will be convenient to discuss some of the general facilities required in physical measurement laboratories first and then, later, specific requirements and layout for various techniques.

GENERAL FACILITIES

Electric Power. The power supply for physical measurement laboratories should receive very careful consideration. In fact, its needs may dictate to some extent the power distribution for the entire building. In addition to flexibility and safety, such laboratories impose other strict operating requirements, such as absence of stray magnetic fields, good wave shape, close voltage regulation, etc. Many laboratories find the general adaptability of three-phase four-wire 120/208-volt distribution most suitable for secondary distribution. One laboratory,* largely devoted to physics research, in its secondary distribution has met the strict operating conditions just mentioned by the use of limiter-protected ring mains in the basement floors, each fed from three 200-KVA three-phase transformers and a spare. From the loop, vertical power feeders rise to the attic at 12-foot intervals, and each room is provided with a 50-ampere circuit breaker. From this circuit breaker, circuits may be run in an exposed wire trough. Common outlets for such a trough are 15-, 20- and 30-ampere, 120-volt single phase; 20- and 30-ampere, 208-volt single-phase, and three-phase. Some laboratories also provide 440-volt three-phase for special power requirements, and various DC voltages. One or more unassigned circuits in the wire trough will be useful in certain installations. Each outlet is commonly protected against overload and short circuit by fuses or by individual breakers (slight delay action) which may also serve as on-off switches.

After careful consideration has been given to the power distribution, the voltage regulation may still not meet all requirements. These needs may frequently be met by individual regulators at the spot where needed. In certain cases the magnetic fields set up by some types of regulators, and the heat dissipated by them, must be avoided. Here one might consider distribution of a regulated supply from a suitably located switchboard over one or more of the unassigned circuits in the wire trough. If at the switchboard several sizes of regulators, 50-watt, 250-watt, 500-watt, 1000-watt, etc., are available, it will permit matching the load to the regulator and also connecting a regulated supply to several unassigned circuits simultaneously. The user, of course, must post a notice that a given regulator and circuit are in use.

Another very satisfactory source of regulated voltage is had through the use of a separate power supply consisting of a synchronous motor driving an AC generator. This generator can be controlled by a suitable voltage regulator, and its output distributed over a switchboard as mentioned above. The Johns-Manville Corporation, Manville, New Jersey, requires very strict voltage regulation in their thermal conductivity laboratory (page 213), and have found the following system satisfactory. The output of a generator is fed into a Wheatstone bridge, two arms of which are nonohmic resistances. An increase in the output of the generator unbalances the bridge, and this unbalance is used to actuate an electronic circuit, which in turn controls the motor-generator unit.

The supplying of direct current is treated in detail in the chapter on electrochemical laboratories. Physical measurement laboratories, however, usually have limited needs for direct current. In some cases 0-125 and 0-250-volt DC is provided from battery installations with suitable equipment for recharging. Frequently, the direct current is provided at the spot through the use of 120-volt single-phase and a rectifier or 208-volt three-phase and a motor-generator.

Closely allied to the distribution of electrical power is the provision for a silent instrument ground in many of these laboratories.

Vibration Elimination. Much physical measurement work requires freedom from vibrations. To achieve this, and other advantages, many organizations are moving to rural areas. Comparative freedom from ground vibrations may be had at suitable distances from railroads and major highways. It is then necessary to see that the type of construction is such that vibrations are not set up in the structure by the wind, and that heavy equipment in the building is installed so as not to cause vibration. After every precaution is taken, thunder storms, infrequent blasting in the neighborhood, and other activities beyond control remain to set up occasional vibrations. For special equipment, concrete piers going down to bedrock, and isolated from the building structure, are ideal, and are frequently provided at basement and first floor levels.†

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* Bell Telephone Laboratories, Murray Hill, New Jersey. For a detailed description of their power distribution see Bell Lab. Rec., 22 273-281 (1944).

† B. F. Goodrich Research Center, Brecksville, Ohio, provided nine such piers for the laboratories of their Physics Division on the first floor of the Research Building (see page 364).

Where some vibration is present there are various means for mounting delicate equipment. Each problem is almost a unique one, and what will satisfactorily solve the problem in one location may be useless in another place. Strong* has discussed the problem of providing vibrationless supports. Actually, a vibrationless support is merely an oscillating system loosely coupled mechanically to the building. The natural period of the support must be long compared to that of the building vibrations, and it is necessary that the support be damped to suppress its own natural vibrations. Julius and Müller suspensions, based on this simple theory, are valuable for mounting sensitive galvanometers. The vibrationless support may take the form of a heavy mass, such as a stone slab or concrete block, resting on a pile of newspapers, layers of sponge rubber, cork, felt or other materials. Shearing friction in the newspapers and internal friction of the rubber and other materials damps out vibrations. Rubber in both shear and compression† is successfully used to stop vibrations near their source, as in mounting machinery.

Photographic Darkrooms and Darkened Laboratories. Many of the physical measurement laboratories require photographic darkroom facilities. These needs are most satisfactorily met by individual darkrooms for each technique. Frequently these can be one-man darkrooms unless the volume of work demands that they be larger. The large darkroom used by several groups is inconvenient and unsatisfactory because of the different light requirements for various photographic materials, the need for different processing solutions for the various materials, and the divided responsibility for keeping the equipment clean and in order.

Suitably ventilated inner rooms are preferred for darkrooms. Outside rooms are more difficult to maintain at constant temperature, and if they have windows it is difficult to make them absolutely light-tight to daylight. They should be equipped with incandescent fixtures rather than fluorescent fixtures for general lighting because the frequent on-off switching will greatly shorten the life of fluorescent tubes. One other very serious objection to the latter is their very appreciable and rather persistent afterglow which is sufficient to fog many photographic materials. The illumination for photographic work is best provided by over-all indirect illumination with the proper safelights together with spot illumination over the loading and developing areas. Dimming arrangements, such as used in theaters, are useful for control of the illumination. Chilled water is a necessity for keeping processing solutions at the proper temperature. If chilled water is not piped throughout the building, special darkroom refrigeration units are available, or a drinking fountain unit may serve as a supply.

Optical measurements, spectrographic work, electron microscopy, and other measurements require darkened laboratories for part of the work. The best solution is to provide inner rooms for certain of these laboratories. Windowless laboratories, of course, simplify the problem. Where only infrequent darkening is required, dark shades in channels‡ provide a very satisfactory solution. The dark shades should have horizontal stiffening stays to prevent them from being pulled from the channels by air currents when the windows are open.

Laboratory Services. Island and wall-shelf types of service installation** with the pipes enclosed are very desirable for physical measurement laboratories. Chemical tables and vacuum or distillation racks are readily installed along the walls or at these service islands at the centers of laboratories. Island service is still more useful for the special equipment of some of these laboratories. In the case of special setups the electrical lines may be run through the wall trough to a central control board at a suitable location in the room.

Common services include drain, cold water, fuel gas, compressed air, vacuum, and steam. It is wise sometimes to provide a filtered water supply for the darkrooms and certain equipment, since sediment and scale from pipes will spot photographic materials and clog screens in the controls of x-ray diffraction units, etc. Some laboratories provide compressed air at say 65 psi, and then filter it and reduce the pressure for actual use. Hot water should be supplied at the sinks, and many laboratories soften it to zero hardness by means of zeolite-resin type softeners. Distilled water is supplied in block tin or aluminum pipes and should have valves which cannot be left open. Special laboratories requiring very high quality distilled water are conveniently supplied by small-capacity individual stills (page 210).

Many laboratories have need for a variety of special gases, and actually pipe oxygen, hydrogen, nitrogen, cracked ammonia, acteylene and others to various rooms from a central source. There is great difference of opinion as to the hazards involved in handling certain of these gases. Some laboratories regard the piping of any of the above, except nitrogen, as too hazardous. They, accordingly, supply them in cylinders which are required to be fastened to the table with suitable fixtures. There is a very definite hazard, however, in handling gas cylinders, so that others regard the possibility of explosion from dropping cylinders as a greater hazard than from piping these gases, even hydrogen and acetylene. For large installations, however, piping seems to be the only satisfactory solution. An oxygen system involving 150 cylinders is shortly to be installed and piped at Battelle Memorial Institute, Columbus, Ohio.

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* John Strong, "Procedures in Experimental Physics," Prentice-Hall, Inc., New York 1945, p. 590.

† Firestone Vibration Dampeners, Firestone Tire and Rubber Company, Akron, Ohio.

‡ An excellent installation has been made at the new Bell Telephone Laboratories, Murray Hill, N. J.

** See "Piping Services at the New Bell Telephone Laboratory," Franklin P. Hunt, Heating, Piping and Air Conditioning, 15 217-219 (1943).

Air Conditioning. Extensive physical measurement work will have an important bearing on the question of air conditioning for the new laboratory building. Aside from the matter of the increased comfort and efficiency of the personnel, air conditioning is a necessity in most of these laboratories because of the special requirements of temperature, humidity, or freedom from dust which the various techniques demand. The air-conditioning ducts should generally be provided with deflectors and diffusers, such as "Anemostats",* to protect the personnel from drafts, and to prevent turbulence, disturbance of Bunsen burner flames, etc. The general conditioned air for the laboratory building as a whole will seldom meet these special requirements, but this conditioned air will be a good initial air supply for further conditioning to the special requirements. For instance, the general air-conditioning unit may be filtering, cooling and dehumidifying the air to conditions for personal comfort. Such dehumidification will usually not be sufficient for infrared spectrographic laboratories, and may not be controlled closely enough for textile testing.

The special requirements can frequently be accomplished in several ways. One new infrared laboratory achieves the required low humidity with an additional refrigeration unit located in the air duct near the laboratory. This unit further dehumidifies the air from the general air-conditioning system. A heater is then provided to bring the dryer air back up to the desired temperature. If a high degree of freedom from dust is required, it is sometimes desirable to take the filtered air of the general air-conditioning system and pass it through an electrostatic type of dust precipitator. In the control of dust, paper filters are usually found superior to the fiber glass type, but, of course, inferior to electrostatic equipment. It is usually easier to maintain these special conditions by systems which recycle a large fraction of the laboratory air. This permits a certain degree of clean up as regards dust, and makes the special humidity conditions easier to maintain. Some type of continuous recording device to indicate temperature and relative humidity should be installed in each laboratory. The Aminco-Dunmore electric hygrometer† is very useful for making instantaneous spot tests of relative humidity in a laboratory.

When the air conditioning has to be done by individual units placed in the laboratories additional space must be planned for the equipment. Also, the vibration and electrical disturbances which may possibly arise from such equipment must be taken into account in its location and installation.

The following table suggests average air-conditioning requirements for those laboratories where air conditioning is considered a necessity.

TABLE III. 1

SUGGESTED AIR CONDITIONING FOR PHYSICAL MEASUREMENT LABORATORIES

Laboratory	Temperature Control	Relative Humidity	Dust Removal
X-ray diffraction	Constancy with comfort	50%	Filter
Electron diffraction	"	50%	Filter
Electron microscopy	"	50%	Electrostatic
Chemical microscopy	"	50%	Filter
Emission spectroscopy (flame photometer)	"	50%	Electrostatic
Infrared spectrometry	76° F	35%	Filter
Textile testing	70±2° F	65±2%	Filter
Plastics and rubber testing	77±2° F	50±2%	Filter
Electrical measurements and electronics	Constancy with comfort	25%	Filter
Vacuum tube research	"	50%	Electrostatic

SPECIAL REQUIREMENTS AND LAYOUT

Physical Chemistry and General Physics Laboratories

After the discussion of general facilities, the laboratory for physical chemistry needs relatively little further comment. The special activities of the particular industry will dictate its size and the general layout of tables and services. With island and shelf service installations the erection of vacuum tables, distillation and ebulliometric equipment, and facilities for gaseous kinetic and adsorption measurements is simple and convenient (figure III.38). A T-shaped table arrangement is frequently very desirable when equipment is to be set up in duplicate. Two pH meters, conductivity setups, Beckman DU spectrophotometers, or other instruments may be arranged opposite each other on the leg of the T (their operators facing each other), while the space along the cross of the T is reserved for preparation of samples for the instruments.

Thought should be given to providing safety shields for certain experimental work. At duPont Experimental Station, Wilmington, Delaware, convenient shields are made from clear lucite sheet. At center tables, where workers face each other, shields of ⅛ inch lucite are suspended along the center line of the table, between the setups of the two workers. Shields for use between the worker and his own apparatus should be of ¼ inch

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* Anemostat Corporation of America, 10 E. 39th Street, New York, N. Y.

† American Instrument Company, Silver Spring, Md.

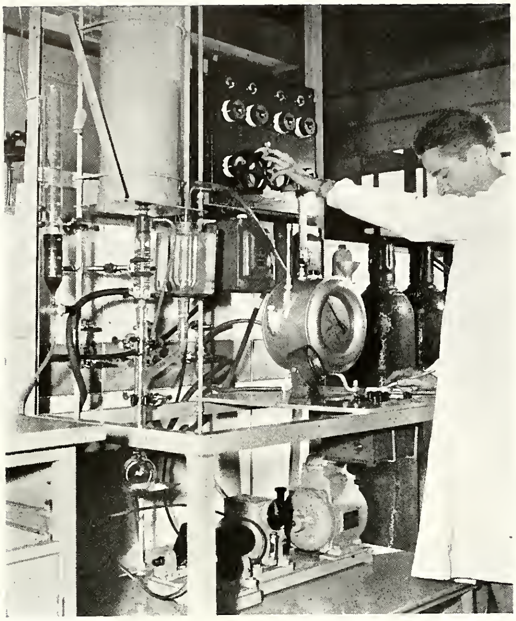

Figure III.38 Catalyst-evaluating apparatus in a laboratory at the new Johns-Manville Research Center (Courtesy Johns-Manville Corporation).

material. These can be made in sections with hinges, and have provision for clamping to the front of the table. Semicircular openings at the bottom permit the removal or adjustment of pieces of equipment without undue exposure of the operator. In addition, other safety provisions, such as goggles, fire blankets and showers, and emergency exits to laboratories, must receive careful consideration. Safety cages should be provided around all high-voltage setups, and all doors to the cages must have circuit-opening devices.

In the general physics laboratory movable tables, which can be arranged into L-shaped, T-shaped, and other groupings to suit the experimental requirements, will be found very useful. The tops of these tables may conveniently be supplied in three materials, built-up wood, wood with "Transite" on top, and "Alberene" stone. Each has its particular utility, but physicists generally will favor the first two. The general problems of electrical facilities and laboratory services have been discussed. It might be pointed out, however, that the enclosed island and shelf for services is particularly convenient for experimental arrangements on grouped tables.

Invariably, a small amount of chemical work has to be done in most physics laboratories. Accordingly, each one should have a chemical table consisting of not less than three 40-inch sections, one of which will usually be a unit with a sink. A common complaint in physics laboratories is that their sinks are too small, a condition which the planner of a new laboratory can easily avoid. Sun shining through windows onto setups of physical equipment is an annoying disturbance which can be avoided by placing the laboratory on the north side of the building or through the use of windowless laboratories. The physics laboratory, as well as the physical chemistry laboratory, needs sufficient closed-cabinet space and small-drawer space for instruments and accessories. Extra-long drawer space is also valuable for maps, drawings, and certain long pieces of equipment.

The Electron Microscope and Electron Diffraction

A complete electron microscope laboratory provides space for the instrument and its accessories, facilities for specimen preparation, darkroom and photographic equipment and office space for the personnel. The instrument is still surrounded by considerable *glamour*, as far as the public is concerned, and some organizations like to have it installed so that it can conveniently be shown to visitors, even, at times, with some sacrifice to convenience of operation. Figure III.39 suggests a minimum layout for a one-man laboratory. The plan is based on two modules of average dimensions, 7′ by 24′. The minimum two-man laboratory would occupy three such modules. The plan provides convenient circulation between the specimen preparation space and the microscope and the darkroom, and between the attractive office space and either the darkroom or preparation space. Visitors can, likewise, be readily shown around the laboratory at any time exposures are not being made. Manufacturers of the equipment can suggest other convenient layouts.

Of paramount importance in electron microscopy is a vibration free support for the instrument. Many users of the instrument, in their present installation, are plagued by vibration difficulties of one kind or another. Some have to turn off air-conditioning fans and other equipment while making an exposure, and others have to be content with impaired resolution because they have not solved their vibration problems. Considerable thought and study as to the location and support for the microscope will be amply repaid in the instrument's performance. A concrete pier going down to bedrock, and isolated from the building structure, was provided for the instrument at the B. F. Goodrich Research Center, Brecksville, Ohio. Others, however, have achieved satisfactory installation without such elaborate construction.

Magnetic and electrostatic fields created by motors, transformers, voltage regulators, DC power lines, and other electrical equipment disturb the electron beam in the microscope, and must be kept at a safe distance. Thus, the instrument's voltage stabilizer must be located at least 8 feet, and preferably as far as 15 feet,

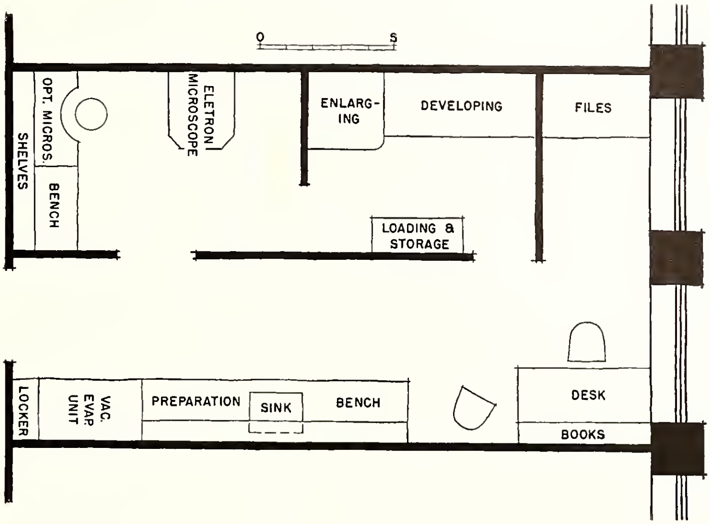

Figure III.39 Suggested layout for a one-man electron microscope laboratory.

away. A shielded room, as at Dow Chemical Company, Midland, Michigan, where the electron microscope room is totally shielded with galvanized sheet iron, is frequently a convenient solution to such problems.

The vacuum pump must be located so as to provide the shortest vacuum line possible, preferably under 6 feet. But the noise of the mechanical pump operating in the same room is distracting and nerve-racking to personnel. It is possible to place the pump in a soundproof ventilated box and overcome this problem. A better solution, however, is to suspend the pump from the ceiling of the room below, or to place it in an adjacent room with the wall between. In the arrangement of figure III.39 it is planned that the vacuum pump would be installed in this fashion. If this is inconvenient, slight changes in the plan would permit placing the pump in a box under the enlarger.

The instrument generates considerable heat during operation so that the laboratory requires air conditioning. Of particular importance is good dust control, for which electrostatic precipitation is recommended. This will avoid contamination of the specimens by dust particles. Most operators would like a small table-type hood to remove solvent vapors during preparation of specimens. The lighting for the electron microscope room as well as the darkroom should be incandescent rather than fluorescent because of the frequent on-off switching. Red warning lights outside the microscope room and darkroom doors to warn individuals not to enter when in use are a convenience. It is well also to provide a small chamber for evacuating loaded cassettes before inserting them in the instrument. The preparations table requires the usual services supplied to a chemical table. The table for an optical microscope is a necessity for preliminary examination of specimens, and it is placed in the darkened space with the electron microscope. The installation instructions supplied with the instrument contain additional details on equipment and layout.

Some of the electron diffraction work in industrial laboratories at present is done with the electron diffraction attachment of the electron microscope. When the technique is taken care of in this fashion, the preceding paragraphs largely constitute an adequate discussion of the electron diffraction laboratory. It must be remembered, however, that the instrument can only be used for one thing at a time, and that the volume of microscope work may well leave little time for its use in electron diffraction studies. Likewise, the diffraction attachment is at times found inadequate for certain studies. Thus, where the volume of work warrants it, far more versatility can be had from a commercially available electron diffraction unit or from experimentally designed setups.

The general layout of the laboratory may still be nearly identical with figure III.39 except that the electron diffraction unit occupies the place of the electron microscope. There is the same need for darkened space (in order to examine the diffraction patterns on a fluorescent screen before making exposures) as with the microscope. The same freedom from stray magnetic and electrostatic fields is necessary as in the case of the electron microscope. Film viewing and measuring equipment will be required for analyzing the diffraction patterns. The other facilities suggested for work in electron microscopy are needed in electron diffraction as well. In setting up separate laboratories in the two techniques it is possible that one vacuum evaporator unit might well serve both. In electron diffraction studies there is rather limited use for the evaporator, but there is a definite need for it at times.

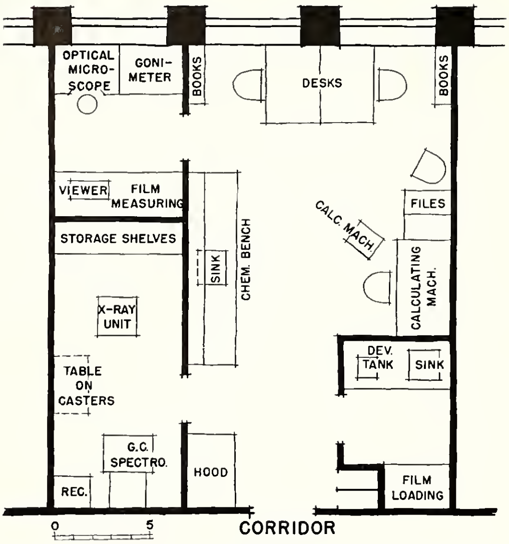

Figure III.40 X-ray diffraction laboratory for two men.

X-ray Diffraction*

A suggested layout for a two-man x-ray diffraction laboratory is shown in figure III.40. It is planned to occupy three modules of average size (7'0" by 24'0") with all walls movable except the outside wall, and services are considered to be supplied from vertical utility stacks in the outside walls. The spaces and facilities as planned are regarded as minimum for a modern diffraction laboratory for research and/or control. The arrangement provides convenient circulation between the preparation space, the diffraction units, and the darkroom. Similarly the film measuring, calculating facilities, and files are handy to the operators' desks. The room for film viewing, goniometric and microscopic work has daylight but may be darkened at will by means of the dark shade.

Adequate storage can be provided in this plan, by means of suitable shelves and cupboards, for all phases of the work except that there is need for storage for bulky equipment items not used daily. For instance, a high-vacuum table on wheels may be used occasionally in preparative work, or thermostats may be needed for constant-temperature diffraction studies. Usually suitable storage, in less costly space on the same floor of the building, can be provided for such equipment. Modification of the floor plan to suit modules of other dimensions will be evident with a little study.

Most domestic commercial diffraction units have a maximum power demand of 2-3 KVA, and can usually be obtained to operate on either 100/130-volt, 50-60-cycle, or 200/250-volt, 50-60-cycle current. Some foreign made units have power demands up to 10 KVA. The number and make of the units will determine the power requirements of the room housing the diffraction equipment. In addition, a 120-volt AC circuit for auxiliary equipment is desirable. A source of water (preferably filtered) with drain facilities is needed for cooling the tubes and transformers. Vacuum for vacuum-back cassettes, and compressed air should be available in this room. The hood and preparation table should have the usual utilities of a chemical laboratory. The table for microscopic work should have 120-volt AC, gas, air, vacuum, water and drain.

In the past, uninformed individuals have occasionally gone to unnecessary expense in their efforts to provide a safe x-ray diffraction laboratory. Some have actually sheathed the entire laboratory in sheet lead to protect the personnel of adjoining laboratories. This is wholly unnecessary, for if radiation of such intensity as to be dangerous to occupants of neighboring laboratories were escaping, how could it be safe for the staff in the diffraction laboratory itself? The laboratory must meet the safety requirements for x-ray diffraction units set forth by the American Standards Association. Modern commercial diffraction equipment is designed to be suitably ray-proof and shock-proof for the operator's protection. All special setups for diffraction studies must be similarly designed to meet these safety requirements. Convenient small electrometer-type radiation measuring devices are available for testing x-ray laboratories.† The operator may wear the detachable ionization chamber all day, and at the end of the day observe just what dose of radiation has been received. In a good diffraction laboratory an operator may work an eight-hour day around the equipment and not obtain as much as 1/10 the permissible daily dose‡ of radiation. Actually, in some laboratories the desks of the staff have been placed in the same room with, and sometimes very near to, the x-ray units. However, there is always some slight scattering of radiation, so that unnecessary exposure, as while doing desk work, is unwise. Accordingly, good planning places the diffraction units inside small rooms away from the preparation and office space. Distance will then decrease small intensities of scattered radiation to insignificant values, and intervening walls plus distance afford considerable protection in case of an accidental direct beam leak.

Industrial Radiography*

The requirements in industrial radiography are so varied that it will be best to refer the planner of such laboratories immediately to a reference work* on the subject and to the literature of radiographic equipment manufacturers. The general run of work is done in a lead-lined exposure room, which must be large enough to accommodate easily the largest objects to be x-rayed. The reference just mentioned (p. 127) suggests a convenient layout for a casting-inspection installation. If gamma-ray radiography is to be carried on, suitable storage facilities must be provided for the radium or other gamma-ray source used. Specifications for radium containers are discussed in the A.S.A. safety code.

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* Planners of x-ray diffraction and radiographic laboratories, as well as their entire staffs, should be familiar with the "Safety Code for the Industrial Use of x-rays," published by the American Standards Association, New York, 1946.

† For example, The Victoreen Minometer. Victoreen Instrument Co., Cleveland, Ohio.

‡ The daily tolerance dose recommended by the U. S. Bureau of Standards Handbook 41 (March 1949) is 0.05 r.

Acoustics Laboratories

Acoustics laboratories are so specialized that it seems desirable merely to describe briefly a recent one in order to suggest the unusual facilities to be considered in their planning. From such a description it will be evident that the planning of this type of laboratory is a piece of research, and hence is beyond the scope of this chapter.

At the Bell Telephone Laboratories,† Murray Hill, N. J., the acoustics laboratory is housed in its own building and has three major parts each with its acoustical laboratory space: 1. free-space room or response measuring space; 2. two live rooms or reverberation chambers; and 3. the listening room, which takes the form of an auditorium.

The free-space room is constructed inside a 40-foot cube of masonry. The walls, floor and ceiling are of 30 layers of fabric suspended with varying degrees of separation. Sound-producing instruments may be wheeled into the room on a track suspended from the ceiling, and measurements made electrically in the adjacent laboratory. The room, however, is completely isolated from the main structure of the building by double bulkhead doors and a 4-inch air space.

The reverberation chambers are similarly isolated rooms with an opening between the two for test panels on which measurements of sound transmission are made.

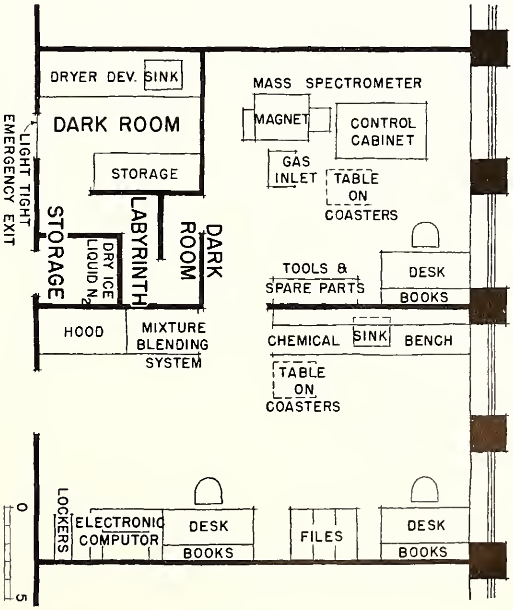
The listening room, while serving as a laboratory, is in the form of a beautiful auditorium. The padded seats give the room essentially the same absorption when empty as when filled to capacity. Since the room is used for public addresses as well as stereophonic sound experiments it was designed to be resonant without annoying reverberation. This is accomplished by absorption areas in the walls and ceiling, and by splayed wall surfaces to break up the reflections. A wall of acoustically-transparent cloth covers the experimental wall separating the platform from the laboratory behind it. Amplifiers and measuring equipment can be installed in this wall. Space will not permit further details of this specialized laboratory, but these brief points suggest the facilities of such a laboratory.

Mass Spectrometry

In discussing laboratory layout for mass spectrometric measurements it will suffice here to make brief suggestions for a workable arrangement involving one of the commercially available instruments. The minimum laboratory for research and control (15-25 samples per eight-hour shift) requires a staff of three. This requires four modules of average size. Figure III.41, based on a Consolidated Model 21-102 mass spectrometer, conveniently provides all facilities needed. To minimize the possibility of accidental damage the instrument should be set up in a separate room close to the sample preparation space. In the suggested layout the darkroom is convenient, while tool and spare parts storage and the operator's desk are arranged for in the spectrometer room. Dry ice and liquid N_2 storage are provided. Sample preparation is handy to the spectrometer, while computing space, record files and desks for the interpretive staff are conveniently near by. The strip-chart recording General Electric mass spectrometer and the manually operated Process and Instruments Model M60 do not require the darkroom, but otherwise the layout is essentially the same.

The mass spectrometer room is preferably air conditioned to provide proper temperature control. Under average operation 4KVA of power is dissipated as heat. While small changes in temperature have little effect on the instrument, large changes, and particularly operation above 90°F, increase maintenance time and decrease operating efficiency. At high temperatures

Figure III.41 Three-man mass spectragraphic laboratory.



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* Ancel St. John and Herbert R. Isenburger, "Industrial Radiology," John Wiley and Sons, Inc., New York, 2nd ed. 1943.

† See New Pencil Points, pp. 47-50, August 1942.

stopcocks require more frequent cleaning and lubrication, evacuation time is increased, and battery and vacuum tube life is decreased.

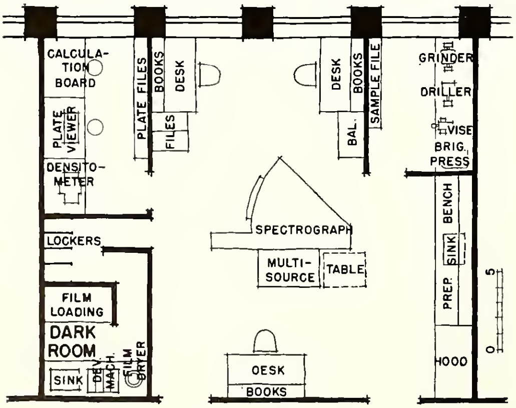
The floor load must be kept in mind in designing a room for the instrument. The 3,000-pound magnet results in a floor loading of 400 pounds per square foot. Some have planned for installation of a heavy floor beam directly under the position the instrument is to occupy. There are no serious vibration problems. Electrical disturbances, such as from unshielded arcs or high-frequency sparks, affect the recording system. The best solution is proper shielding at the source of the disturbance.

The power requirement is a 115-230 volt, 60 cycle, single-phase 3-wire lighting circuit of at least 5 KVA capacity. For protection of the instrument this is best supplied through an isolation transformer. The spectrometer room also requires water, gas, compressed air and drain. A filter and a constant-pressure regulator are desirable on the water line. The gas is required near the instrument for use in glassblowing and making ground joints. Makers of the instruments should be consulted for futher details on layout and installation.

Optical Spectroscopy

Emission Spectroscopy. Although there are several different types of emission spectrographs commercially available, the technique is sufficiently standardized that it is possible to suggest a typical laboratory layout. Figure III.42 gives a plan for an emission laboratory suitable for research and semi-control work. This represents minimum space requirements for a three-man laboratory and occupies four average size (7'0" by 24'0") modules. Sample preparation is conveniently arranged on the right side of the laboratory, the arcing and exposure facilities are in the lower left corner, while the plate measurement and interpretive equipment is in the upper left of the plan. One individual might well be placed in charge of each of these aspects of the work, and, accordingly, occupy the desk space adjacent to these facilities. For laboratories with a large volume of analyses it may be convenient to consider arrangements which incorporate the plate or film holder of the spectrograph inside the darkroom. Manufacturers of emission spectrographic equipment can offer additional suggestions as to laboratory layout.

Figure III.42 Emission spectrographic laboratory for staff of three.



It is generally agreed that air conditioning with good dust removal and humidity control (50%) is required. The arcs should have hoods to remove fumes and dust, and safety protection for the operating staff both from the electrical current and actinic rays. Many laboratories will want to operate their flame photometers in the emission laboratory. This instrument, too, appears to require freedom from atmospheric dust for best results. The ashing of samples demands a hood with its lower openings at the proper height to carry away the fumes efficiently. Some laboratories* are making very considerable use of infrared lamps for evaporation and ashing operations. Although slower than other procedures, the infrared process can readily be carried all the way to the stage at which the sample is ready for insertion in a muffle furnace for its final ignition. A sugar solution, for instance, can be evaporated and ignited without the formation of the usual black puffy mass.

High quality distilled water is required in an emission spectrographic laboratory. This is conveniently furnished by a small still in the laboratory. At the Dow Chemical Company, Midland, Michigan, doubly distilled water from an all-glass still is found satisfactory.

There is difference of opinion as to the desirability of refrigerating spectrographic plates to prevent deterioration. It is known that changes in sensitivity occur when plates undergo temperature changes shortly before exposures are made. Some laboratories refrigerate only those plates with the less frequently used emulsions, and rely on rapid turnover and frequent restocking of the commonly used plates to insure against deterioration and aging. Other general features of the darkroom are discussed on page 204.

An idea of the power requirements for operation of the spectrograph can be obtained from the input specifications of a multisource unit: 5KVA, 230-volts, 60-cycle, single-phase.

Provision for occasional darkening of the laboratory by means of dark shades in channels is very desirable for such operations as alignment and adjustment of the optics of the spectrograph. It is a convenience to have the viewing and densitometering equipment in a separate room which can be darkened as desired. The plate viewing table with a milk-glass fluorescent unit set

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* Eastern Regional Research Laboratory, U. S. Department of Agriculture, Philadelphia, Pa.

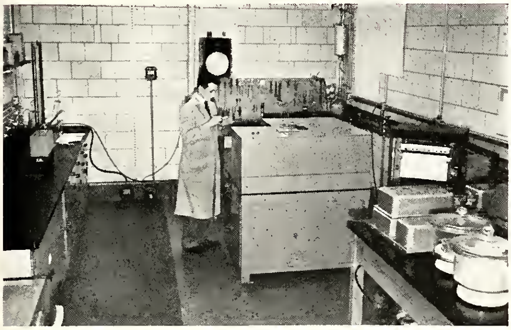

Figure III.43 A view in the laboratory for infrared absorption spectroscopy at Mellon Institute.

flush in the top is handy for comparison of several plates at one time.

Infrared Spectroscopy. The most important special requirement of the infrared laboratory (figure III.43) is temperature and humidity control. While the rock-salt and potassium bromide windows of infrared instruments become only slightly less transparent to ordinary wavelengths of the infrared region as a result of exposure to a humid atmosphere, there are more serious aspects to the temperature and humidity problem. Among these are the need for low humidity when changing optics and working on the interior of the spectrometer, the nuisance of the changing water vapor in the beam path with humidity changes, and, finally, the possibility that the instrument may breathe with changes of temperature and damage the optics in spite of desiccants placed inside the case. Accordingly, most laboratories try to maintain a relative humidity of about 35 ±2%, although some are striving for as low as 25% and others are content with values up to 45%. Some of the spectrometers also are decidedly temperature sensitive, so that, considering the humidity requirements, a good year-around attainable operating temperature is 76°F.

The laboratory, in general, does not require electrostatic shielding unless there are unshielded or incompletely shielded microwave or high-frequency laboratories in the vicinity. Planned space for filing is desirable, and a tabletop with an opal-glass fluorescent unit built into it is most convenient for working on curves and traces.

Ultraviolet Absorption Spectroscopy. Instruments such as the Beckman DU, General Electric, and Cary spectrophotometers can be set up in any convenient laboratory space.

Raman Spectroscopy. There are no special requirements for the Raman laboratory aside from facilities for darkening the laboratory and cooling to take care of the heat from the low-pressure mercury vapor arcs using for illuminating the sample. They may be water cooled, or air conditioning may be arranged to take care of this additional heat.

Electrical Measurements and Electronics

Electrical measurement laboratories, including those for various types of electronics studies, are assuming increasing importance industrially. There is the feeling in planning for them that low relative humidity is important for the ultimate in accuracy, and some laboratories are air conditioning for as low as 25% relative humidity. Careful electrostatic shielding (including filters in the power lines) is needed to prevent microwave and high-frequency laboratories from being a disturbance to other types of electrical measurements. The location of a commercial broadcasting station in the vicinity of the laboratory may demand shielding for certain work. The special instrument ground mentioned on page 203 is very desirable.

A special feature at the B. F. Goodrich Research Center, Brecksville, Ohio, is a wiring bench for electronics work. This bench is provided with 110-volt AC with 5- and 20-ampere instantaneous breakers, also with 220-volt single-phase and 440-volt three-phase. Two Variac-Controlled circuits supply 0-135-volt AC, and through other circuits rectified 110-220-volt DC is supplied from the 440-volt line. The bench is built to convenient height for standing workers, and has drawer space below for resistors, condensers, and other small electronics parts. A niche in the back provides space for a test set. Battelle Memorial Institute, Columbus, Ohio, in an electronics laboratory now being built, has provided the assembling bench at such height that workers may sit at it while wiring, soldering, etc. The testing bench, which they are attempting to arrange in duplicate, has oscilloscopes, a variety of oscillators, power supplies, frequency meters, tube testers, and other test meters arranged on shelves on the wall and ready to be instantly attached to the equipment being tested.

Physical Testing

Physical testing covers such a variety of tests and equipment in various laboratories that it is impossible here to make more than a few suggestions indicating general trends in these laboratories. The size, and especially weight of the equipment determines to some extent the location in the building of the testing laboratory. Laboratory buildings are commonly designed for floor loads of 125-175 pounds/square foot with occasionally a load limit of 250 pounds/square foot for the first floor. Obviously, light testing equipment can be installed at any level, but heavy equipment must be placed in the basement where, if necessary, the supports can go down to bedrock. The heavy equipment is likely to bring up the problems of vibrations and large energy dissipation as heat, so that some organizations have placed the heavy testing in their engineering research building.

The laboratory for heavy testing should be located so that the service leads for power, steam, water, etc. can be as short as possible. In general, creep and flow

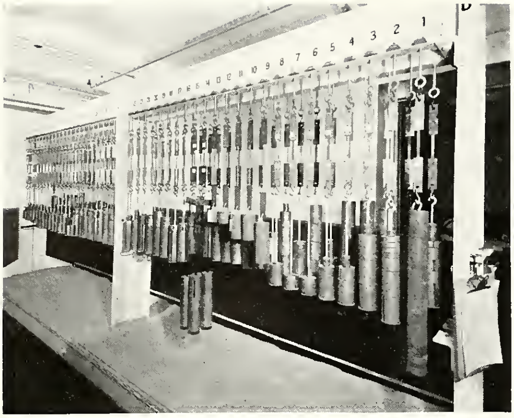

Figure III.44 Longtime tensile or creep tests. Basement laboratory with frame supported by bedrock (Courtesy Bell Telephone Laboratories).

testing equipment (figure III.44), large tensile and compression machines, impact machines (which should weigh 100 times the impact load), and fatigue testing equipment (figure III.45) should be on the ground floor and directly connected to a good earth foundation. This reduces building vibrations and solves problems of high floor load.

Power dissipation is such a problem that some maintain certain laboratories at 85°F the year around. It may be possible by careful planning to separate some of the equipment by partitions from the space in which operators have to work. The latter space could then be air conditioned while the equipment space could be allowed to go to a somewhat higher temperature. Several of the rubber companies have solved a similar problem in connection with their processing presses in this way.

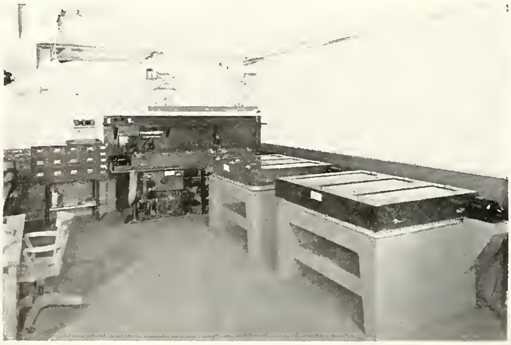

Figure III.45 Machines for fatigue tests on lead. The heavy concrete bases reduce the effects of vibration, and motor generator set is for control of power (Courtesy Bell Telephone Laboratories).

The power requirements for certain tests have to be met by special arrangements. Regulators can be used for voltage control of the AC supply. The direct current needed can be obtained from a motor-generator set with a suitable regulator operating from the three-phase 208-volt AC (figure III.45).

The plastics and rubber industries have reached agreement on a standard atmosphere* (77±2°F and 50±2% R.H.) for testing laboratories, and many of these laboratories follow A.S.T.M. specifications in their testing. The wisdom shown by these and other industries in standardizing tests and techniques is most highly commendable, and the need for further standardization is still most urgent. In general, their equipment is light enough to be located any place in the building, but special air conditioning is necessary to maintain the standard conditions.

The A.S.T.M. standard conditions for textile testing are 70±2°F and 65±2% relative humidity.† Good humidity control is especially needed because sudden humidity changes are very bad for textile testing. Test measurements on single fibers and filaments require, in addition, low velocity of the conditioned air. "Anemostats" help in decreasing air velocity and turbulence. The special air conditioning required is often more easily maintained by a system which recycles a large portion of the air. A cold room and a very dry room are additional desirable features of textile testing laboratories.

The precision gauge laboratory, sometimes a part of the physical testing laboratory, should be in air-conditioned space.

Instrument Calibration Laboratories

The reliability of physical measurements depends on the accuracy of the instruments being used. In many laboratories, however, instruments that have not been calibrated in years are in daily use. In fact, the condition of the laboratory standards in many excellent laboratories, both academic and industrial, is a scientific disgrace. Furthermore, there is no excuse for such a state with the excellent facilities of the National Bureau of Standards so readily available for calibration and certification service. Part of the difficulty results from the common custom of permitting all staff members to have access to the standards, although the great majority of the staff have little knowledge of their proper handling and of calibration methods. In other cases the standards have not had recertification for many years. Certainly one can have little confidence in a set of standard weights that has not been recalibrated in fifteen years.

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* A.S.T.M. Standards on Plastics—Committee D-20, September 1948, p. 174. A.S.T.M. Standards on Rubber Products—Committee D-11, February 1948, p. 507.

† A.S.T.M. Standards, 1947 Supplement, Part III-A, page 43.

The calibration laboratory should have its own staff whose sole responsibility is the maintenance of the laboratory standards and the periodic calibration of every type of measuring instrument in use. The standards, obviously, should not be handled or used by anyone outside of this trained staff. In general, two or more standards of each type, i.e., Weston cell, standard ohm, resistance thermometer, etc., should be provided. These should be returned periodically in rotation, say one each year, to the Bureau of Standards for checking and recertification. At frequent intervals they can also be compared among themselves to catch changes in their calibration values. This sort of procedure in competent hands will maintain an excellent set of primary standards for a laboratory. In some cases it will be satisfactory to calibrate secondary standards from the primary ones and use only the former for the routine calibration.

Certain calibrations which are done in the largest volume, such as ammeters, voltmeters, and the like, may be arranged in permanent setups ready for instant use. It may, however, be necessary to dismantle some equipment and set it up as needed, if space is limited. If possible, each instrument should be checked once every six months, and oftener if any question of its accuracy should arise. Where an instrument storeroom which loans equipment is maintained, it may be possible to check certain items of equipment every time they are sent out, and it is particularly important if an instrument is out on loan for a long period to call it in long enough for its periodic check up.

It is hardly necessary to enumerate the calibration services of such a laboratory but it should cover the whole range of measuring instruments from stop watches to heavy testing machines. In the case of the latter, and other instruments in permanent installations, the tests must be made by taking the calibration equipment to the location. Such laboratories may also be prepared to make, as well as calibrate, certain measuring apparatus, such as thermocouples, resistance heaters, vacuum gages, etc. Finally, they can provide for the staff a valuable consulting and advisory service on all phases of precise physical measurement. An outstanding calibration laboratory is maintained by Battelle Memorial Institute, Columbus, Ohio.

Miscellaneous Physical Measurement Laboratories

It is obviously not possible to discuss, even briefly, in a single chapter all of the many techniques which fall in the general category of physical measurements. However, in the course of laboratory visitation and correspondence in connection with this project, brief suggestions and information have come to hand on several less common types of laboratories.

The electroencephalograph, it was pointed out, requires darkened space, darkroom facilities, electrostatic shielding, and air conditioning. One laboratory in powder metallurgy reports the desirability of air conditioning for the powder testing laboratory.

Figure III.46 Control room switchboard of Johns-Manville's thermal conductivity laboratory (Courtesy Johns-Manville Corporation).

Optical laboratories, generally, need special facilities. A grating laboratory, for instance, requires darkened space, concrete piers and vibration free supports, as well as air conditioning. The lens testing laboratory also needs darkened space and a photographic darkroom.

Cryogenic and low-temperature laboratories are in such a special class that even the specialist in the technique will want to study at first hand recent installations before designing a new layout. Descriptions of several laboratories of this type have appeared in the literature.*

Laboratories for thermal conductivity measurements require very strict voltage regulation (page 203), because a small voltage error can lead to a significant error in the apparent power consumption of the heater, and hence to an appreciable error in the thermal conductivity determination. At the Johns-Manville Research Center, Manville, New Jersey, two separate controlled-voltage motor-generator units have been provided, one to serve the thermal conductivity laboratory (figure III.46), and one to serve the remaining physics laboratories which require a regulated voltage supply. These units are wired so that either can be connected to the other circuit in the event of a breakdown or failure, but they normally operate independently.

Seismological laboratories require concrete piers for equipment, special construction to avoid vibration, air conditioning, and photographic darkroom facilities.

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* "Description of the Liquid Hydrogen Plant at the Clarendon Laboratory, Oxford." Jones, Larsen and Simon, Research, 1 420-432 (1948). "Cryogenic Laboratory," Herrick F. Johnston, Ohio State Univ., Eng. Expt. Sta. News, 18, No. 3, 3-21 (1946). "Cryogenic Laboratory at the National Bureau of Standards," F. G. Brickwedde, Ibid. 18, No. 3, 30-34 (1946). "Cryogenic Laboratory at Leiden," Robert Guillien, Smithsonian Inst. Pub. 3421 177-184 (1937).

7

THE DESIGN OF LABORATORIES FOR THE SAFE HANDLING OF RADIOISOTOPES

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The large-scale development of atomic energy during the last war introduced many new and difficult problems in the design, construction and operation of the laboratories connected with the Manhattan Project. Of these diverse problems, the handling of radioactive† materials (more commonly called radioisotopes) proved to be one of the most difficult. With the advent of widespread distribution of radioisotopes by the Atomic Energy Commission, the problem of handling radioactive materials safely became one of nation-wide interest. Although the use of these materials within the Atomic Energy Commission involves quantities up to thousands of curies,† the average radioisotope user is concerned with much smaller quantities. Since this book is intended for general usage, this chapter will be limited to a discussion of laboratories intended for use of radioisotopes in quantities and of the types normally available from cyclotrons, nuclear generators, or the Atomic Energy Commission nuclear reactors. These radioisotopes usually are beta† and gamma† emitters and in quantities not over 100 millicuries.†

It is well to note that, because of the broad scope of the problem of radioisotope laboratory design, this chapter can only point out some of the salient specifications and requirements. It is recommended that the Isotopes Division of the Atomic Energy Commission or other suitable authorities be consulted before detailed plans are made.

GENERAL CONSIDERATIONS

The introduction of radioisotopes into a laboratory usually requires special considerations to 1. protect personnel from the radiation hazards associated with the material and 2. prevent the invalidation of experimental data. The philosophy of eliminating these potential problems in the laboratory is not alien to researchers. In fact, the "aseptic" techniques of a bacteriological laboratory and the lead shielding of a radium laboratory are readily adaptable to the conditions of radioisotope work. The special considerations required for a radioisotope laboratory involve the control of radiation fields and contamination, both of which may affect the health of personnel or the validity of experimental data. The control of radiation and contamination usually is accomplished by the use of:

A. Properly designed laboratories and equipment.
B. Properly adapted operational methods and techniques.
C. Applied procedures for detecting and maintaining satisfactory working conditions in relation to radiation fields and contamination.

Each of these items is of equal importance in the successful operation of a radioisotope laboratory. The discussion in this chapter will be concerned principally with the design of laboratories. References to the allied phases of laboratory operation will be found in Appendix IV.

Since the various radioisotopes are used in a multitude of forms and have a wide variety of nuclear, chemical, physical and biological properties, no set specifications can be established for what constitutes "proper" design, technique or regulation. Therefore, specific considerations for a laboratory must be on the basis of the isotopes to be used, the quantities of them present, and the particular properties they possess. These properties in reference to radiation and contamination are:

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* Present address: Naval Radiological Defense Laboratory, San Francisco, Calif.

† See Appendix I for the definition of this term and others used throughout this chapter.

A. *Radiation:* Isotopes emit radiations of various types (principally beta and gamma rays) and at different energies. These radiations exhibit a wide range of absorption characteristics which determine the health hazards and the precautions necessary to alleviate them.

B. *Contamination:* Small portions of the isotopes may escape the main body of the material to pollute laboratory surfaces, air, or personnel. The degree of contamination is dependent, of course, upon the physical and chemical properties possessed by the isotope, the compound it is in, or the operation or technique used to handle it. According to the radiation and biological characteristics of the isotope, these contaminations may invalidate data and/or present a health hazard, both of which must be prevented.

In addition, other factors, such as the chemical toxicity of the material, complexity of operations performed, etc., are important.

To analyze these factors and, from them, evolve a laboratory that is designed and operated efficiently is a complex problem. However, in general, laboratories can be divided into three types: those where only radiation is a problem; those where only contamination is a problem; and those where radiation and contamination both present a problem. It is well to point out that general purpose laboratories must be designed to consider both radiation and contamination. However when it is possible to predict the specific function of a laboratory, it is more economical to base the design upon that function alone. The following descriptions roughly outline the principles for laboratory and furniture design and construction. Also included are some of the handling techniques used for such work. The details of applying these principles are discussed in other sections of the chapter.

PROBLEMS IN LABORATORIES WITH ONLY A RADIATION PROBLEM

In laboratories where radioactive materials are used only for the radiation fields they provide, the sources of activity are usually tightly sealed and present no problem from a contamination standpoint.[*] Such radioisotopes are used for radiation sources in biological studies, radiography, or instrument calibration. A typical radioisotope that might be used for this purpose, because of its high-energy radiation and long half-life, is Cobalt 60. Unlike most isotopes, it is potentially available in quantities up to several curies. Laboratories in which such sources are to be used should have construction characteristics somewhat similar to those of laboratories containing x-ray machinery or nuclear generators. Such a laboratory should be designed for the protection of personnel and certain units of the experimental equipment from excessive radiation dosages. According to the latest recommendations[†] as of this writing, radiation dosages in excess of 300 milliroentgens (mr) of gamma radiation, or its equivalent,[‡] per week, are unsafe.

This is usually expressed more conveniently for establishing safe working conditions as 50 mr per day or 6¼ mr per hour. However, it is usually considered advisable to maintain the dosage rate in the laboratories at considerably lower levels. As an example of the radiation dosages encountered in a laboratory of this type, calculations indicate that only about 0.4 mc of Cobalt 60 will produce the permissible dosage rate at one foot when the gamma rays alone are considered.

In general, the reduction of radiation dosage rate can be accomplished by maintaining a sufficient distance between the source and the recipient, by interposing shielding, or by regulating the time of exposure.[**] The method of incorporating these factors in the design will depend upon the operational techniques and equipment to be used in the laboratory. For radiation fields of low intensity, laboratory tongs can be used to handle the source, thus keeping sufficient distance between the source and the researcher. If the source is somewhat more radioactive, hollow cylindrical shields of absorbing material,[§] fitting closely around the source, can be used to reduce the field. If it is impractical from an operational standpoint to use such shielding, barriers or walls of lead or steel bricks can be erected. In such a case, all operations should be performed with tongs bent to extend around or over the barrier without exposing the operator.

When the activity levels are considerably higher (for instance, about 100 millicuries of Cobalt 60), the radiation control facilities should be built into the laboratory. These facilities must be designed to give safe storage and operation of the source.[§§] The storage of such a radioactive source may be in a lead or concrete vault, a well in the floor, or other comparable installation. In any case, the storage system must be designed so that the dosage rate in the room is at a conservative level. The operation and use of such a source must take place behind a heavy wall or at a considerable distance, and the facilities must be designed to protect all personnel, either directly connected with the experiment or otherwise, from excessive dosages of radiation. Table III.2 shows the radiation fields to be anticipated from various quantities of Cobalt 60 and indicates the techniques of handling such quantities.

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[*] Small amounts of contamination may be present on the outside of the container, due to contamination at the processing plant. Even solid metallic sources should be sealed as corrosion or oxidation of the surface will release small particles of contaminate.

[†] Recommended by National Committee on Radiation Protection, sponsored by the National Bureau of Standards.

[‡] The tolerance dosage rate for beta radiation is expressed as 300 milliroentgens equivalent physical per week.

[**] A concise explanation of the calculations required for shielding may be found in Isotopes Division Circular B-4, "Some Practical Considerations in Radiation Shielding," by G. W. Morgan.

[§] Different materials are usually used for different types of radiations: e.g., lead, steel, concrete for gamma rays, and glass, plastic, aluminum, etc., for beta particles. See Isotopes Division Circular B-4.

[§§] Design computations are usually based upon 10% of the permissible dosage rate in working areas. This allows a safety factor to correct for scattering, etc. In addition, when the gamma emitting isotope to be used has not been established, a 2 Mev energy is assumed for calculation purposes.

The design of a laboratory involving only a radiation problem may have to incorporate the following features, depending upon the quantities and type of radioactive material used; and the use and purpose of the same:

A. Special permanent barriers, probably of concrete, which incorporate viewing devices, remote control apparatus, etc.
B. Storage vaults or walls, with means of removing the source by remote control.
C. Floors capable of withstanding heavy loads of temporary barriers or shipping containers.
D. Sufficient shielding or isolation of the building to protect persons not connected with the program from extraneous radiation fields.

PROBLEMS IN LABORATORIES WITH ONLY A CONTAMINATION PROBLEM

Many laboratories, principally for biology, chemistry or physics, handle radioactive materials that present no external radiation hazard because their very low energy emissions will not penetrate rubber gloves.*

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* Range of C-14 and S-35 in aluminum is 20 milligrams (mg) per sq.cm. and 13.5 mg/sq.cm. respectively; W. F. Libby, "Measurement of Radioactive Tracers", Analytical Chemistry, January, 1947.

TABLE III. 2

OPERATING CONDITIONS FOR DIFFERENT QUANTITIES OF COBALT 60

Quantity of Co-60 mc	Dosage rate @ 1 ft mr hr(1)(2)	Est. Amount of Shielding Reqd. inches (1)	Working Distance ft.	Est. Weight of Lead Shield (3) lbs.	Remarks
.5	7	—	1	—	18" tongs to be used
2.5	35	1" lead	1	9	18" tongs used with close shield or use barrier if source must be moved
		—	2½	—	36" tongs used
25	350	2½" lead or 11" concrete	1	72	Barrier required and operation with bent tongs or remote control apparatus
		—	7½	—	8 foot tongs or remote control
100	1400	3½" lead or 14" concrete	1	170	Barrier with remote control
		—	15	—	Remote control reqd.
1000	14000	4⅝" lead or 20" concrete	1	390	Barrier with remote control reqd.
		—	48	—	Remote control reqd.

(1) Estimated from chart in Isotopes Division Circular B-4 using 6¼ mr/hr as tolerance dosage rate.
(2) Neglecting the beta radiation from the disintegration.
(3) Based upon an assumed source size of 1" dia. x 1¼" long (about 1 cu. in.).

However, these materials can be dangerous if they are inhaled, ingested or otherwise taken into the body. The most widely used isotopes of this type are C-14 and S-35. The tolerance dosage rates are again based upon the value of 300 mr per week for any part of the body. When dealing with internal radiation of the body, extremely small quantities may produce tolerance doses of radiation.

Internal contamination of the researcher can result from the breathing of contaminated air, handling contaminated equipment or touching contaminated tabletops, walls, floors, etc. Permissible contamination levels have been recommended* for beta and gamma emitting materials as follows:

Air	10^{-6}, uc/liter
Water	10^{-4}, uc/liter

In addition, the Atomic Energy Commission has established a permissible contamination level for exposed surfaces, floors, tabletops, etc., at 2000 disintegrations per minute for 150 sq. cm.†

Often, of more importance to the researcher is the danger of technical contamination (i.e., the cross-contamination of experimental material). It is possible for one-billionth of an initial radioisotope shipment to invalidate a final counting sample by several hundred per cent. When such is the case, the tolerance levels shown above are by far too high. Consequently, the researcher must establish his own contamination tolerances to maintain freedom from the danger of invalidating his experiment.

Contamination can be prevented to a great extent by the use of proper operational equipment and techniques. If possible, closed system apparatus or gloved boxes (see figure III.47) should be used. The use of auxiliary trays, absorbent paper, and similar equipment will tend to eliminate the spread of contamination to laboratory surfaces.

In a laboratory presenting only a contamination problem, the design is based upon both the prevention of contamination and its easy removal.

PROBLEMS IN LABORATORIES WITH BOTH RADIATION AND CONTAMINATION PROBLEMS

Most of the laboratories employing radioisotopes fall into this category. Since many of the radioactive materials used in chemistry, biology and therapy emit high energy radiations and are in forms that can be spread easily, both radiation and contamination problems must be considered in the design and operation of the laboratory. In general, the principles of control of radiation and contamination remain as outlined in preceding sections, the principal exception being that the materials used for radiation control should be nonporous and corrosion resistant. In addition, contamination by materials emitting high energy radiations may present a radiation hazard.

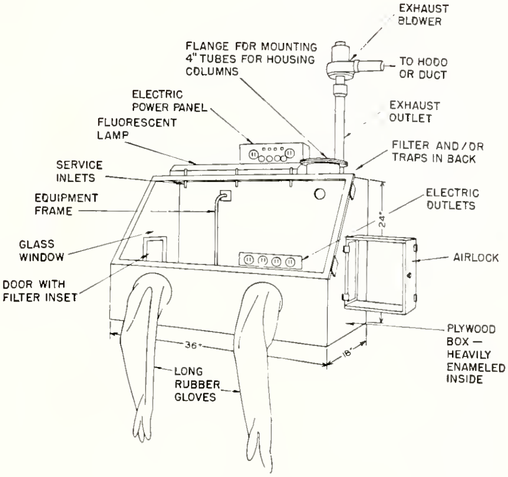

Figure III.47 Gloved box for soft beta work.

The operations performed on materials presenting both radiation and contamination hazard are usually done with tongs, with the radioactive material being kept in close shields or behind barriers. Radiochemical hoods are used to prevent the spread of contamination and to carry off noxious and hazardous fumes.

The joint application of the principles outlined above is in some cases incompatible. For instance, while gloved boxes afford one of the most effective means of contamination control, their adaptation for use with tongs and shielding is very difficult and expensive at the present time.

SCOPE OF DESIGN PROBLEM

The principles outlined in the preceding sections may be applied to a laboratory unit in many ways, although the final requirement is in every case the perpetual maintenance of safe and efficient working conditions. The areas of a laboratory or building that require special considerations are the ones that are subject, however remote the possibility, to radiation fields or contamination. If the isotope user is positive that in his work the radiation and contamination can not extend by any means beyond his one piece of apparatus, only that equipment needs special considerations. That case is the exception. Often, however, the contamination and radiation can be limited to a definite gloved box, hood and/or tabletop, or can be confined to one or two rooms. In other instances, whole floors or buildings

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* Safe Handling of Radioisotopes, Report of National Committee on Radiation Protection, sponsored by the National Bureau of Standards.

† Standard Safety Requirements, Atomic Energy Commission Regulations, Safety No. 3, Item 14.05-B-1, page 251, April 28, 1947.

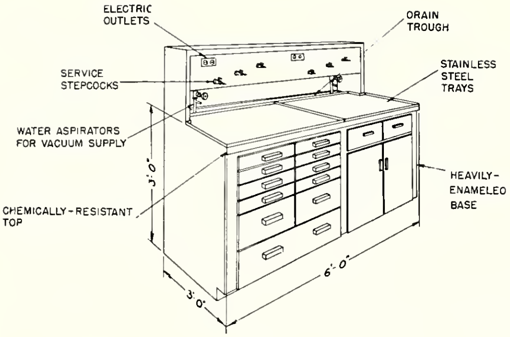

Figure III.48 Radiochemical laboratory table.

must be designed to take care of these conditions. Consequently, every possibility of contamination spread or extraneous radiation field must be investigated carefully to determine the scope of the problem.

RADIOISOTOPE LABORATORY FURNITURE

The smallest unit of a radioisotope laboratory unit requiring consideration other than the actual processing and handling equipment is usually the furniture. Of course, the working surfaces are of prime importance, but such possibilities as spills, equipment breakage, and the scattering of radioactive dust or vapor beyond the working surfaces must be anticipated. Depending upon complexity of the contamination and radiation control problem, and the funds available, the laboratory furniture should be of special design and construction or of converted standard equipment.

Laboratory Tables:

The tables used in radioisotope laboratories are usually very similar to standard chemical tables, the only alteration being the addition of a non-porous metal-sheathed top and/or metal trays completely covering the working surfaces. Other alterations, such as sealing the cracks and joints with plastic-backed adhesive tape and repainting various surfaces to reduce porosity are often done. The use of disposable surfaces, such as paper, strippable paints, etc., often provide an economic "first line of defense."

However, tables meeting the optimum specifications for radioisotope work should have stainless steel-sheathed working surfaces, free from joints and with a high lip around the four sides. The drain trough can be eliminated or the outlet stoppered with overflow plug to reduce the possibility of contaminating the sewage system. The table can be made 3 feet wide to provide distance protection for low level operations. It should be of strong enough construction to withstand the load imposed by heavy shields. The use of a chemical shelf and exposed piping should be avoided as they present areas that are easily contaminated. In some cases, it might be wise to eliminate the cabinets and drawers, leaving only the legs and stiffeners under the table-top. Figure III.48 shows a table similar to that used in Oak Ridge Institute of Nuclear Studies.

Fume Hoods:

For laboratory operations that evolve gases, fumes, or splatters that may be radioactive, a so-called radiochemical hood should be used. Such a hood is usually the general shape and size of a standard fume hood. However, it should be constructed of non-porous materials, and be as free of cracks as possible. Chemical resistance is required if the gases or fumes are at all corrosive. Wood or asbestos board construction can be used if it is treated for porosity and the cracks are covered over. Enameled aluminum or steel may prove satisfactory for some installations, and stainless steel can be used if HCl fumes are not present in appreciable quantities. Atomic Energy Commission regulations* stipulate that the flow rate across the face of a hood used for radioactive materials should be about 100 linear feet/minute, which is somewhat higher than that normally specified for chemical laboratories. Service outlets should be located near the hood opening, with the controls outside of the hood proper. Such facilities as inset steam tables are not advisable because they are difficult to decontaminate.

Figure III.49 shows the details of the hoods used in the Oak Ridge Institute of Nuclear Studies. While they do not meet the specifications completely, they have proved very satisfactory for tracer-level work.

In populous areas, it is advisable to filter or otherwise entrap any particulate radioactive material from the exhaust air. Such filters should be installed as close to the hood outlet as possible to keep the contaminated area to a minimum. Air cleaning systems are discussed in detail in the "Heating and Ventilating" section.

The tables used in conjunction with the hoods should meet the specifications of the laboratory tables. Figure III.49 shows an alternate table with a well to be used for opening isotope shipments. (It eliminates the need of lifting the shipping container to table height.) Such a well is useful for isotope storage or for long-column work.

A "California" type of hood is often used for glass vacuum-line equipment for organic synthesis. While such equipment is normally safe to use when handling gaseous radioactive materials, the hood is important in case of breakage. Figure III.50 shows a typical "California" type hood.

For work with open vessels containing radioactive materials with low energy radiations, gloved boxes (see figure III.47) are desirable. They are in reality small, totally enclosed hoods that keep any contamination localized. Operations are performed by the use of

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* Standard Safety Requirements, Atomic Energy Commission Regulations, Safety No. 3, Item 14.06-A-3, page 251, April 28, 1947.

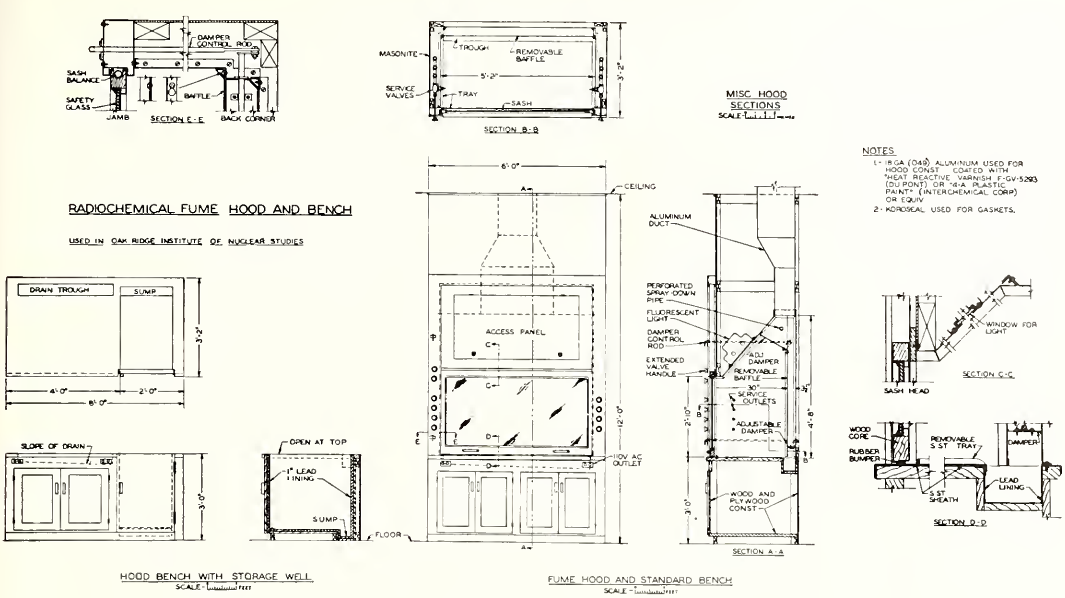
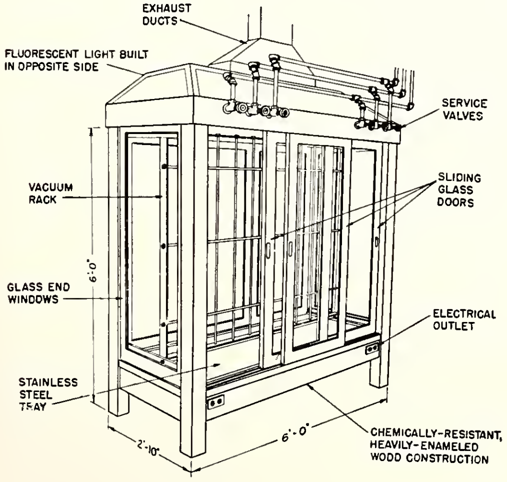


Figure III.49 Radiochemical fume hood and table.

rubber gloves mounted in the box. Shields are placed around any containers of radioactive materials that emit hazardous radiations. The air inlet should be small enough to provide a minimum of 100 to 150 linear feet/minute air velocity through the inlet for general purpose operations. Since the flow rate is low, small fractional horse power blowers can be used and the contaminated air can be easily filtered or trapped before it is discharged into a manifold or standard hood.

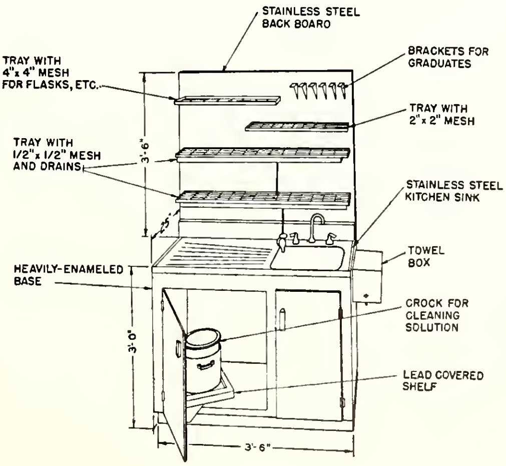
Figure III.50 California type hood.



Dishwashing Sinks:

Non-porous, chemically resistant materials should be used for dishwashing sinks (see figure III.51). Hot and cold, as well as distilled water, should be supplied. Foot controls or knee controls for the water should be used if hand contamination is a possibility. Screen wire trays are preferable to peg boards for drying glassware. Cleaning solutions should be set in a special well or on a tray fastened to the cupboard door.

Figure III.51 Dishwashing sink.


STAINLESS STEEL BACK BOARD
TRAY WITH 4"x 4" MESH FOR FLASKS, ETC.
BRACKETS FOR GRADUATES
TRAY WITH 2"x 2" MESH
TRAY WITH 1/2"x 1/2" MESH AND DRAINS
3'-6"
STAINLESS STEEL KITCHEN SINK
TOWEL BOX
HEAVILY-ENAMELED BASE
CROCK FOR CLEANING SOLUTION
3'-0"
LEAD COVERED SHELF
3'-6"

RADIOISTOPE LABORATORY CONSTRUCTION AND LAYOUT

The arrangement of furniture and equipment within a radioisotope laboratory is also conditioned by radiation fields and the possibility of contamination. For the efficient operation of a radioisotope laboratory, the following rules can be established:

A. Radiation detection instruments used for experimental measurements should not be subjected to unnecessary or varying radiation fields or to the possibility of contamination.

B. The operations, as well as the handling equipment, glassware, furniture (including dishwashing sinks), work areas, etc., for handling different quantities or types of radioactive materials in forms that may allow contamination should be physically segregated at all times.

As a rule the application of these fundamentals imposes upon the laboratory additional space requirements. In fact, the segregation often requires the use of several small rooms, rather than one large room. In addition, when widely varying quantities of radioisotopes are used in different phases of a project, several complete hood, table and sink units may be required for each level of activity. Subsequently, the space and furniture assigned per man in the laboratory may be greater. Another consideration arising in the layout is the increased ratio of hood space to table space. This is required because of the necessity of performing many more operations in the hood than are normally done in standard laboratory practice.

In a typical layout, the radioisotope laboratory unit may be made up of a shipment receiving and dispensing room, a tracer laboratory, a sample preparation room, and a counting room. Of course, laboratories for other purposes may require animal farms, dissection rooms, synthesis rooms, irradiation rooms, etc. For large installations, special facilities for changing clothing, decontamination, instrument repair, etc., may be needed. Regardless of the use of the various rooms, they should be arranged so that radiation fields and contamination will not impede the work performed. This involves grouping the furniture, equipment and supplies for each activity level within the room. As much as possible the rooms should be arranged to keep the rooms of maximum potential contamination as far as compatible with efficient operation from rooms where the contamination possibility is low.

Interior Construction Requirements:

The walls, floors and ceilings of a radioisotope laboratory where contamination is to be considered should be smooth, and have a minimum of cracks, corners, projections, etc., to prevent the entrapment of radioactive materials. The construction materials should be chosen to give non-porous surfaces in all cases, and as much chemical resistance as is required by the process involved in the laboratory. Walls and ceilings may be heavily painted to reduce porosity. Wooden floors cannot be used satisfactorily because of the cracks and porous surface. Although they all have limitations, linoleum, asphalt tile, and vinyl tile, are preferable for floors.

HEATING AND VENTILATING

The large air volumes required by fume hoods make heating and air conditioning difficult and expensive. For this reason, air conditioning is used only where it is a necessity. The ventilating system should be designed to introduce a flow pattern within the building so that the air flow is from rooms and corridors containing no active material into those containing active material. This of necessity involves a complicated control system. The flow pattern within the individual rooms should be designed to avoid drafts across the face of the hoods. In new buildings, an overhead plenum system is sometimes used to introduce air through perforated ceilings.

Hood ducts, blowers, filters and stacks should be considered as part of the ventilating system. Any of the ducts or blowers subject to contamination should have the same material and construction specifications as the radiochemical hoods. Motors should be mounted outside of the fan housing for ease of maintenance. As previously stated, in some installations it may be necessary to remove any contamination from the air before it is discharged. Filters are used most frequently, but they introduce a number of disadvantages; they provide a large volume of material to be disposed of; they present a hazard due to the possible spread of contamination upon their removal, they require larger blowers, and they require periodic checks of the air flow to determine clogging. However, they provide the most satisfactory method of air cleaning at present, but there are indications that more efficient filter media will be commercially available soon. Scrubbers, in general, serve the same purpose as a filter, but they are expensive to install, and introduce the problem of disposal of large volumes of contaminated water. Electrostatic precipitators have the disadvantage in that the waste material is not collected in a disposable form. For this reason they must be periodically washed down, and contaminated waste water again results. However, if the concentration of active material in the waste water from scrubbers and electrostatic precipitators is kept below certain limits (see waste disposal section), it can be disposed of by standard methods. If no type of cleaner is used on the contaminated air, the stacks or outlet ducts should discharge well above the surrounding buildings. The flow pattern of the gas out of the stacks should be investigated carefully to determine if the surrounding area may become contaminated. In some cases, the rate of release of radioactive material by the process can be controlled to maintain a permissible concentration in the air discharged from the stack.

WASTE DISPOSAL SYSTEMS

The problem of the disposal of radioactive wastes must be considered during the design of a laboratory, even though the problem is, primarily, one of procedure and regulation. At this time, regulations have not been established concerning the methods of waste disposal. The isotope user is committed, however, by moral and legal* considerations to prevent the contamination of the public domain. This means that if the researcher allows the release of radioactive wastes into air, public sewage systems or waterways, he must be sure that it will present no hazard to any one at any time. While dilutions can be made to reduce the waste to below tolerance concentrations, reconcentration of the radioactive elements in the order of 10^5 can take place in specific locations by biological, bacterial, chemical or other means. For this reason, the disposal of radioactive wastes indiscriminately is to be discouraged.

The best guide to the proper means of waste disposal now available is the tentative recommendations† made by an advisory group to the Division of Biology and Medicine, Atomic Energy Commission. While these recommendations are incomplete and not expected to be "permanent,"‡ they do indicate what may be typical of future regulations.

Sewage System:

The disposal of liquid wastes in sewage systems of short-lived radioactive materials other than the radioiodine and -phosphorus specifically mentioned in the recommendations in Appendix II can be assumed to follow the same general pattern; that a concentration of 0.1 uc/liter not be exceeded and the isotope be adulterated with the stable isotope in the same chemical form and in a quantity sufficient to prevent the assimilation of the radioactive isotope by the human body in hazardous quantities.**

Since the recommendations were prepared primarily to prevent hazardous conditions in the sewage system leading from the plant or institution, the problem must be considered also in the design of the building. If the final dilution of radioactive waste takes place in the main sewer from the building, higher concentrations will be present in piping within the building and reconcentrations may take place. Any entrapping of active material within the plumbing may result in extraneous radiation fields. For this reason the most satisfactory location for the main disposal sink is as near the main sewer as possible. This shortens the run of pipe and takes advantage of the greatest dilution. If the sewer system of disposal is used, the plumbing should be constructed to the following specifications:

A. Chemically resistant and non-porous piping should be used.
B. Horizontal runs should be avoided to prevent entrapment.
C. Joints and traps should be accessible for radiation surveys and for detection and repair of leaks.
D. Sinks should be made of chemically resistant, non-porous materials.

Burial Grounds:

The interim recommendations also stipulate that burial of radioactive waste is permissible if the waste is suitably adulterated. Appendix III lists the quantities of stable isotope required to dilute some isotopes to the required concentration.

Solid wastes, such as contaminated equipment, paper, filters, etc., although not specifically mentioned in the recommendations, may require their being sealed in corrosion-resistant cans or cast in concrete blocks.

Such a burial ground will have to be the property of the isotope user and should be suitably fenced-in. Of course, the drainage pattern of the area should be investigated to determine the possibility of contaminating a water supply.

Storage for Decay:

A waste disposal system that is essentially independent of any regulations is that of retaining any active wastes for at least ten half-lives. Assuming the average user will be faced with the disposing of a millicurie or smaller quantity of waste, the decay will reduce the quantity by a factor of a thousand, or that of a microcurie, or less. This quantity is much easier to dispose of than the original millicurie. This general philosophy implies that for short half-lived materials only a temporary storage is required, but for long-lived materials, a permanent storage is indicated.

Many laboratories will find need for a storage room, not only for waste material, but for unused portions of shipments and for contaminated equipment and glassware. If isotopes of energetic radiations are used, the radiation fields must be considered. While lead-lined or concrete walls are sometimes recommended for such rooms, their necessity may be questionable. If the radiation fields are such that heavy walls are required to reduce the dosage rate outside of the room, the dosage rates within may be excessive, even for short exposures. It is felt that if the radioactive sources are stored in individual shields of concrete blocks, lead bricks, or close-shields, the dosage rate both outside and within the room can be kept at a safer level. Large rooms will allow the dispersal of radiation sources, thereby reducing areas of high activity.

Such a room should of course be easily decontaminable. Shelves may be provided for storage of small items. The room should be kept locked, and radiation surveys made each time it is entered. Whenever additional radioactive material is added to the room, radiation surveys should be made both inside and outside the room.

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* See Item 2 of "Acceptance of Terms and Conditions for Order and Receipt of By-Product Materials (Radioisotopes)," Isotopes Division, Atomic Energy Commission.

† See Appendix II.

‡ The National Committee on Radiation Protection, sponsored by the National Bureau of Standards, is charged with the responsibility of preparing permanent regulations.

** The determination of these values consider the biological concentration and retention of the element, the half-life and energy of the radiations. Values other than those for radioiodine and radiophosphorus are not available at the present time.

Incineration:

The interim waste disposal recommendations imply that the incineration of active material is permissible if the stack gas is of the specified concentration or less. This means that the exhaust flow rate and the rate of release of active material during incineration be known. Since the disposal of C-14 particulate matter is expressly prohibited, filters must be provided. Presumably, if the ashes retain active material, they must be disposed of by burial or other means.

Preliminary Processing of Wastes:

In some cases, radioactive material may require processing to make its disposal easier or more foolproof. Various means of preparing waste solutions for disposal may be used:

A. Concentration of liquid wastes by precipitation or evaporation, where the radioactive matter is concentrated into solid waste, which in turn must be disposed of.

B. Concentration of liquid waste by ion exchange, where the waste is passed through an ion exchange column. After the exchange resin is completely "charged", the active material can be eluted off in a small volume of liquid or the resin can be disposed of as solid matter.

C. Enclosure of material in concrete, where the waste material is mixed with liquid concrete and poured into metal drums lined with uncontaminated concrete. This can be used for either solid or liquid wastes. When the drums are full and capped with "pure" concrete, they can be stored, buried, or otherwise disposed of.

If conditions warrant, separate rooms should be provided for each of the above processes. Of course, both radiation and contamination should be considered in the room and equipment construction. The use of these systems undoubtedly will be conditioned by the final waste disposal regulations.

As indicated in the above sections, the disposal of radioactive wastes is in a very controversial state. A careful investigation of the latest regulations should be made before any extensive design is attempted in a radioisotope laboratory

EXAMPLES

A better appreciation of the application of the principles of radioisotope laboratory design and operation can be gained by describing several hypothetical setups.

Example of a Laboratory for the Use of About 1 Curie of Cobalt 60:

For a program to study the porosity of hollow steel castings with the radiations of Cobalt 60, the procedure is assumed to be as follows:

A. The castings are wrapped with special sensitized paper.

B. The Cobalt 60 is placed in the center of the casting.

C. The photographic paper is removed, developed, and examined for flaws in the castings.

The laboratories for this work present no special considerations except those in the exposure laboratory. This room is about 15 feet square and has concrete walls about a foot or more thick. The building has only a single story, so the roof is not made of shielding material. The Cobalt 60 is stored in a well in the floor. The well has a lead plug to shield the source. The castings are set over an opening in a table over the well. A mirror system allows an operator outside of the room to view the operations safely. The plug and source are removed from and replaced in the well by a system of pulleys and cables to the operating area.

Example of a Laboratory for the Use of Carbon 14:

For a program involving the distribution of an organic compound within an animal, the procedure is assumed to be as follows:

A. The original C-14 shipment (as $BaCO_3$) is synthesized into an organic compound.

B. This compound is injected into rats, most of the C-14 being excreted or exhaled by the rats.

C. The rats are sacrificed, various organs are isolated and the amount of C-14 in each determined by counting.

Since Carbon 14, when handled with rubber gloves to stop the radiations, presents only a contamination problem, the laboratories are designed for those specifications. However, to decrease the possibility of cross-contamination of the experimental material, the operations are segregated in different rooms as to activity levels.

The synthesis room: In this room, the shipment is processed and the compound synthesized. The injections are performed here also. Because the quantities of C-14 are relatively large (1 millicurie or more) and the contamination a definite possibility, this laboratory is designed for the most exacting contamination control. Operations on the $BaCO_3$ are done in gloved boxes. The C-14 is transferred from the gloved boxes in a closed container to the glass vacuum-line synthesis equipment in a "California" hood. After the compound is prepared, the injections are made in a gloved box on a separate laboratory table. The structural materials in the laboratory are all non-porous. Waxed linoleum or tile floors (with the joints sealed) are used. The walls and ceiling are heavily enameled. The gloved box exhaust air is filtered and trapped. The ducts for the hood are non-porous and free of cracks. The laboratory tables are painted and the tops are of stainless steel or other non-porous materials.

The animal room: The animals are stored here both before and after injections. The segregation of animals in a separate room is not necessarily one of activity level but rather one of sanitation. While no radioactive materials as such are handled in the animal room, there is considerable possibility of contamination from the excreted and exhaled CO_2. Consequently, the injected rats are kept in a cage in a ventilated gloved box. The cage is designed to catch all excreta. The interior of the gloved box is non-porous. The other rats are kept in standard cages. The floors and walls are heavily painted to facilitate any decontamination. The contaminated cages are cleaned in a tank separate from that used for the uncontaminated cages.

The dissection room: The sacrificing, dissection and the counting samples preparation are done here on separate tables. The counting is done in a separate room. (Note: climatic conditions may require the counting to be done in a temperature and humidity controlled room.) Because of the small amount of C-14 present in the rats, gloved boxes usually are not required. However, the autopsies are performed over glass or stainless steel trays. The sample digestions and evaporations are done in a radiochemical hood or gloved box. The floors are linoleum or tile and the walls and ceilings are heavily painted.

The waste material of the laboratory is incinerated in a special filtered incinerator and under special regulations to limit the Carbon 14 concentration to permissible levels.

Example of a Laboratory for the Use of Iodine 131:

A laboratory for the use of Iodine 131 requires the consideration of both the radiation and contamination problems.

A typical research program would be the study of the solubility of an iodine compound in various solvents.

The experimental procedure is assumed to be somewhat as follows:

A. The Iodine 131 shipment is processed to prepare the desired compound.

B. This compound is then diluted to the desired concentration, and portions of it pipetted into suitable extraction units.

C. The extraction units are operated as per specifications, and samples of the liquids taken.

D. These samples are processed and "counted."

Again, the operations are segregated according to activity level. However, the laboratories must be designed to accommodate a radiation as well as a contamination problem.

The isotope preparation and experimental room: This room is used for the preparation, the dilution and proportioning of the desired compound for the experiment. The experimental work is performed in this laboratory, but the extractor units are taken to the tracer room for sampling. It is assumed that about 100 millicuries of I-131 are in the compound and the extractions are carried out at the 100 microcurie level. Therefore, the operations necessary to process the shipment and prepare the compound require shielding. Because of the volatility of I-131, the operations are done in a radiochemical hood. Once the compound is diluted and placed in the extractors they are handled with short tongs (probably 6 or 8 inches long). The extractors are tightly stoppered, and the extractions are performed in a radiochemical hood in case of an accident. The laboratory surfaces are non-porous, as described in the second example, but since the compound is somewhat acid, the surfaces must also be chemically resistant. Two stainless steel dishwashing sinks are in the laboratory. The glassware used for the initial operations is cleaned in one sink and the extraction glassware in another. This is to segregate the glassware to prevent its cross-contamination. A corner of the room walled in on four sides by lead bricks is used for the storage of bottles of waste solutions.

The tracer room: The sampling of the extraction solutions, as well as the sample preparation, are done in this room. The solutions are sampled in one radiochemical hood and the samples dried in another. Again, glassware and other equipment require segregation. Although shielding is not needed, the walls, floor, etc., must be non-porous and chemically resistant.

The counting room: Because of the contamination possibility in the tracer room, the counting instruments are kept and operated in this room. Assuming the climatic conditions are variable, the room is temperature and humidity controlled. (Temperature 75 ± 2 degrees Fahrenheit, humidity 45 ± 5 per cent.)* Otherwise, the room is standard except that a constant-voltage transformer is required in the 110 volt A. C. supply.

The waste disposal: Because of the short half-life (8 days) of the I-131, the waste material is stored in the preparation room until the activity has decayed until it can be disposed of safely.

Conclusions

The safe use of radioisotopes in a laboratory is conditioned by the design of the laboratory, the operational techniques and equipment used, the rules and regulations employed, and proper use of radiation detection instruments. The purpose of this chapter has been to point out very briefly some of the design specifications for the laboratory. These specifications, however, vary widely with many conditions. Anyone attempting to design a radioisotope laboratory must work closely with the scientists who will use it. Their knowledge of the nuclear and chemical properties of the material is invaluable. In addition, the economy of the design will be determined by the operating rules and techniques to be employed. Basic decisions as to the allowable tolerances of contamination and radiation exposure, the waste disposal procedure, etc., should be made before the design has been started. Only then does the engineer or architect have something upon which to base his decision.

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* Some commercial instruments are designed so that they are not temperature or humidity dependent. If these instruments are used, the air conditioning may not be necessary.

The principles set forth in this chapter are somewhat conservative when compared to those of some laboratories using radioactive materials. The extent to which precautions are taken to prevent hazardous conditions to either personnel or the experiment are usually dependent upon economic factors. However, experience has proved that operations can be performed more efficiently and safely when the laboratory and equipment do not impose too many limitations on the techniques used. In addition, the cost of removing and replacing contaminated walls, floors and furniture will be more expensive than the original installation of resistant surfaces. The loss of research time while such alterations are being done or through invalidated data should also be considered in the economics of laboratory design.

The lack of persons experienced in the handling of radioactive materials has required the Isotopes Division of the Atomic Energy Commission to establish an Advisory Field Service Branch. The purpose of this branch is to collect and disseminate pertinent information on the techniques of using radioisotopes and upon the design of laboratories. Before a design is started, they or other authorities should be contacted for the latest information available.

Appendix IV lists references pertinent to the design of radioisotope laboratories.

APPENDIX I

Absorption: The dissipation of the energy of radiations by interaction of the radiations with matter.

Beta Rays or Particles: High speed electrons emitted by the nuclei when atoms of some radioactive substances disintegrate.

Curie: A curie is that quantity of radon (0.66 mm^3 at 0°C and 760 mm) in radioactive equilibrium with 1 gram of radium. As applied to other radioactive substances, the curie has come to mean the quantity of material that has the same disintegration rate as 1 gram of radium. Thus, 1 curie of P-32, C-14, etc., is the amount of isotope necessary to provide 3.7×10^{10} disintegrating atoms per second. It is to be noted that recommendations have been made that the term "Rutherford" (1 Rutherford (rd) $= 1 \times 10^6$ disintegrations per second) be used for radioisotopes not of the radium family. However, since the usage of this term is not yet widespread in comparison to the "curie," the "curie" will be used herein.

Disintegration: The process of spontaneous nuclear change in which nuclear particles are given off from the nucleus, leaving the nucleus with a different atomic number.

Dosage Rate: A convenient means of expressing the strength of radiation fields in terms of the rate of energy dissipation (milliroentgens per hour).

Electron-Volt: The unit of energy used in nuclear science. Nuclear reactions usually involve energies of the order of millions of electron-volts (abbreviation, Mev). One Mev is equivalent to 1.60×10^{-6} ergs.

Gamma Ray: A non-material, electromagnetic radiation that is a natural consequence of some nuclear disintegrations.

Half-Life: The length of time it takes a quantity of radioactive isotope to decrease to half of its original amount by radioactive disintegration.

Isotopes: Atoms of a given element which have different numbers of neutrons in the nucleus and therefore differ in mass or weight.

Mev: See electron-volt.

Microcurie: One-millionth of a curie.

Millicurie: One-thousandth of a curie.

Milliroentgen: One-thousandth of a roentgen.

Radiation: Material (i.e., beta rays) and non-material (i.e., gamma rays) emitted by the nucleus during the process of disintegration.

Radiation Field: The series of radiations emitted by a group of radioisotopes during their disintegration. This is usually expressed in terms of dosage rate.

Radioactivity: The phenomenon of giving off radiation during the spontaneous disintegration of atomic nuclei.

Radioelement or Radioisotope: An element with the nucleus in an unstable state and which is capable of converting the nucleus to a stable state by disintegration.

Roentgen: A measurement of radiation dosage, the roentgen (r) is that quantity of X or gamma radiation which, when falling on dry air (STP), produces ionization to the extent of one electrostatic unit of either charge per cc of air. One electrostatic unit is equivalent to 2.083×10^9 ion pairs.

Roentgen-Equivalent-Physical (rep): Is the unit of energy dissipation of radiation particles (alpha, beta, proton, neutron) in tissue. One rep corresponds to the absorption of 83 ergs per gram of tissue.

X-Rays: Invisible, penetrating, high-frequency light rays.

APPENDIX II

RECOMMENDED INTERIM PROCEDURES FOR THE WASTE DISPOSAL OF RADIOACTIVE MATERIALS BY OFF-COMMISSION USERS

Although the National Committee on Radiation Protection is formulating recommendations on waste disposal, it was felt that some tentative procedures should be provided for use until these recommendations are available. To assist off-Commission users of radioisotopes during this interim period, the Atomic Energy Commission called a meeting of some leading authorities to formulate disposal procedures. The recommendations made by this group are limited in scope and are subject to amendment as further data and disposal experience dictate. They are interim recommendations, and will eventually be superseded by the recommendations of the National Committee on Radiation Protection.

I. DISPOSAL OF RADIOIODINE

A. Recommended Procedures:

1. Radioiodine may be discharged from an institution into the main sewer, provided:
   - a. The daily volume of water flowing from the sewage outlet of the institution to the main sewer is sufficient to dilute the radioiodine to 0.5 microcurie per liter;
   - b. Maximum activity disposed of from any one institution will not exceed 200 millicuries per week;
   - c. Regular radiation surveys are made of plumbing fixtures;
   - d. Appropriate surveys are made before repairing the plumbing between the disposal outlet and the main sewer;

or

2. Radiodine may be discharged from an institution into the main sewer, provided:
   - a. To each millicurie of radioiodine discharged, one gram of potassium iodide is added at the time of disposal;
   - b. The daily average volume of water flowing from the sewage outlet of an institution to the main sewer is sufficient to dilute the radioiodine to 10 microcuries per liter;
   - c. Regular radiation surveys are made of plumbing fixtures;
   - d. Appropriate surveys are made before repairing the plumbing between the disposal outlet and the main sewer.

II. DISPOSAL OF PHOSPHORUS 32

A. Recommended Procedures:

1. Radiophosphorus may be discharged from an institution into the main sewer, provided:
   - a. The daily volume of water flowing from the sewage outlet of the institution to the main sewer is sufficient to dilute the radiophosphorus to 0.1 microcurie per liter;
   - b. Each millicurie is diluted with 10 grams of phosphorus as phosphate at the time of discharge. (*Note:* The stable phosphate considered in the dilution may be material both naturally and artificially supplied);
   - c. The maximum activity disposed of in any one institution does not exceed 200 millicuries per week;
   - d. Appropriate radiation surveys are made before repairing the plumbing between the disposal outlets and the main sewer;
   - e. The sewage does not enter directly into fresh water systems.

III. DISPOSAL OF CARBON 14

A. Recommended Procedures:

1. Radiocarbon may be exhausted into the air, provided:
   - a. No person shall be exposed to the inhalation of air containing greater than 10^{-5} microcuries per cc;
   - b. Particulate matter is filtered from the exhaust air.

IV. DISPOSAL OF ANY RADIOISOTOPE

Study over a period of years will be required to derive disposal procedures for each radioisotope under all the various circumstances that may arise. Certain possible procedures that were brought up for discussion are as follows:

A. Dilution with stable element to a very low rate of energy dissipation.

1. Radioisotopes of any half-life may be buried in the earth if they are uniformly diluted with stable isotopes of the same chemical element and in the same chemical form, to the extent that 4.15 ergs are dissipated per gram of element* per day,† provided that:
   - a. The burial is made only in suitably selected areas which are in possession of, and will be maintained by, the user;
   - b. The material is buried at a minimum depth of 5 feet.

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* See appendix 111.

† This rate of energy expenditure is equivalent to 50 mrep in the medium per 24-hr. period.

B. Dilution with stable element to a specific activity, below a value which will not permit the body to reconcentrate the activity above permissible values.

C. Disposol in concrete mixture and burial in the earth or at sea.

The interim group was not able to give full consideration to the establishment of quantitative criteria for these possible procedures in the case of all radioisotopes involved. However, it was agreed that procedure IV. A. 1 above can certainly be considered on the safe side.

APPENDIX III

RADIOISOTOPE DILUTION

DILUTION OF ELEMENT REQUIRED TO ACHIEVE 4.15 ERGS/GRAM/DAY IN DILUENT

Isotope	Total Absorbable Energy per Disintegration	Kilograms of Diluent per mc of Isotope
C-14	.051	62
P-32	.558	680
I-131	.645	787
H-3	.005	6
S-35	.056	68
Ca-45	.083	101

Note: 4.15 ergs/gm of tissue is considered a safe permissible daily dose.

APPENDIX IV

PARTIAL LIST OF REFERENCES RELATING TO THE DESIGN AND OPERATION OF RADIOISOTOPE LABORATORIES

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The Fundamentals of Radioactivity, C. J. Overbeck, *Instruments, 21*, 82-85 (January 1948).

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Determination of the Energy of Beta Particles and Photons by Absorption, L. E. Glendenin, *Nucleonics, 2*, 12-32 (1948).

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Safe Handling of Radioisotopes, National Committee on Radiation Protection, sponsored by the National Bureau of Standards.

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The Tolerance Dose, S. T. Cantril and H. M. Parker, MDDC 1100.*

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Control of Radioactive Hazards, W. H. Sullivan, *Chemical and Engineering News, 25*, 1862 (1947).

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Preparation and Measurement of Isotopic Tracers (A Symposium Prepared for the Isotope Research Group), D. Wright Wilson, A.O.C. Nier, and Stanley P. Reimann, *J. W. Edwards*, Ann Arbor, Michigan (1946).

"Hot Lab" Instrumentation, Claude R. Schwob, *Instruments, 20*, 712-713 (1947).

Administration and Operation of a Radiochemical Laboratory, F. C. Henriques, Jr., and A. P. Schreiber, *Nucleonics, 2*, 1-15 (March 1948).

Control of Radioactive Contaminations in Laboratories Using Radioactive Isotopes, W. B. Lewis (Report No. H.R.A.C. 35).

Techniques in the Use of Carbon 14, W. J. Dauben, James C. Reid, and Peter E. Yankwich, *Analytical Chemistry, 19*, 828-835 (November 1947).

The Handling of Radioactive Materials in the Experimental Biology Section, P. C. Tompkins, et al., MDDC 377.*

Laboratory Handling of Radioactive Material, P. C. Tompkins, MDDC 1414.*

The Laboratory Handling of Radioactive Material; Protection of Personnel and Equipment, P. C. Tompkins, MDDC 1527.*

Techniques in the Handling of Radioactive Isotopes Used in Medical Therapy and the Preparation of Radioactive Colloidal Gold, G. W. Sheppard and P. F. Hahn (November 1947), Isotopes Division Circular A-3.†

Equipment for Radiochemical Operations, E. R. Tompkins (June 1948), Isotopes Division Circular A-6.†

Laboratory Design:

Some Aspects of the Design of Radiochemical Laboratories, H. A. Levy, *Chemical and Engineering News, 24*, 3168 (December 10, 1946).

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"Introductory Remarks"—J. A. Swartout

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"Semi-Hot Laboratories"—N. B. Garden

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"Remodeling a Laboratory for Radiochemical Instruction or Research"—H. A. Levy

"A Laboratory for Preparation and Use of Radioactive Organic Compounds"— C. N. Rice

"Some Considerations in the Design of Radio-Biochemical Laboratories"—W. P. Norris

* Most MDDC and AECD reports may be purchased from the U. S. Atomic Energy Commission, Document Sales Agency, P. O. Box 62, Oak Ridge, Tennessee. Also available is a semimonthly publication, Nuclear Science Abstracts, which lists abstracts from reports by the Atomic Energy Commission and from articles appearing in published literature, pertaining to atomic energy.

† Isotopes Division Circulars on the techniques and uses of radioisotopes available from U. S. Atomic Energy Commission, Isotopes Division, P. O. Box "E," Oak Ridge, Tennessee.

8

CONSTANT-TEMPERATURE-HUMIDITY ROOMS

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Daily and seasonal indoor temperatures and relative humidities vary greatly. In an unconditioned building summer and winter seasons present quite different conditions in the northern states. During the summer months the indoor relative humidities do not generally vary greatly from those outdoors and average about 65%. The relative humidity is frequently quite high at night and on rainy days. In the winter, however, the humidities in heated buildings are very much lower because the cold outdoor atmosphere contains little water vapor and when it is heated to normal inside temperatures low relative humidities result.

Many materials and instruments are affected by these changes. Certain materials absorb and give off moisture, depending on the prevailing atmospheric conditions, and changes in weight, dimension, and mechanical properties result. Wood, paper, textiles, and cereals are examples of such materials. The growth of small organisms, plants, animals, and insects is affected by temperature and, in some cases, by relative humidity, so that studies involving them are facilitated by the use of controlled conditions.

It is intended in this chapter to indicate and discuss some of the factors that should be considered in designing and arranging rooms for temperature and humidity control in new laboratory structures. The discussions are based very largely on experience with 12 rooms at the Forest Products Laboratory that have been in use for a number of years.

It is not intended to give specific design data, since there are many ways of accomplishing the same results, and many kinds of materials that might be used in the construction of rooms. It is hoped that the chapter will present general methods available and indicate important things that should be taken into account in preparing such rooms.

Manufacturers of mechanical equipment have qualified engineers who can supply the engineering design of rooms and equipment.

ROOM DESIGN

Where possible, rooms should, of course, be located as near as possible to the sections making use of them. If, however, a number of rooms are needed, it is sometimes desirable to group them together to simplify the mechanical equipment serving them.

Space away from exterior walls, windows, floors, or ceilings is also desirable, if possible, for the location of rooms, since conditions can then be more easily and accurately maintained than when the rooms are affected directly by outdoor conditions. This is especially true where high humidities are a requirement, since cold surfaces may act as condensers that remove water vapor from the space, and may make the maintenance of the desired conditions difficult or impossible.

Room Size

Rooms for controlling temperature and humidity should be of such size as to afford sufficient storage, aisle, and working space for all present and future needs. When the room is to provide for the conditioning of material, aisles should be arranged along walls to prevent storing material against them. Material placed against outside walls will be affected by the temperatures on the exterior side, and, consequently, the intended conditioning environment will not exist. Room ceilings should be made as low as possible; where high ceilings are necessary, special care should be taken to provide air circulation that will maintain uniform temperatures throughout the room. If suitable air circulation is not provided in a heated room, the temperatures will be lower at the floor than at the ceiling, and, as a consequence, the relative humidity will be higher at the floor level than at the ceiling and the moisture condition of stored material will vary accordingly.

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* Maintained in cooperation with the University of Wisconsin.

Room Types

The majority of temperature-controlled rooms are used at ordinary temperatures, but some are required for special uses at high or low temperatures. Variable-temperature rooms are sometimes required for cycling conditions and for use when different conditions are required for periodic testing. The latter kind can be made reasonably satisfactory, however, and better control usually can be obtained if conditions are not changed through too wide a range. In many cases it is better to provide two or three rooms to meet different conditions than to attempt to vary the atmosphere of a single room.

Humidity rooms may be designed with or without temperature control, depending on the service needed. If rooms are to be used for conditioning materials to a definite moisture content, temperature control may be neglected if the relative humidity is regulated by the use of some form of a hygroscopic element. Variable relative-humidity conditions can be readily obtained, but, as in the case of constant-temperature rooms, it is generally recommended that separate rooms be provided when different conditions are needed. Cycling schedules can generally be provided by suitable controls for research programs requiring them.

Thermal Insulation

Where controlled rooms are to be maintained at nearly room temperatures, only a moderate amount of thermal insulation is needed, since heat losses are not likely to be great.

In the case of rooms used for low temperatures, special care should be taken to provide enough thermal insulation to prevent objectionable heat losses and to make smaller refrigerating equipment possible. Floors, walls, and ceilings may require attention in this respect.

The thermal insulation should be designed so as to make sure that the inside surface of the room will never drop below the dew point of the highest relative humidity to be maintained.

Methods of designing the thermal insulation of walls, floors, and ceilings are given in the Guide of the American Society of Heating and Ventilating Engineers* and in other publications. The method of estimating critical wall temperatures is, however, not frequently given. For this reason the following formula is given here.

$$t_s = t_i - \frac{R_i}{R_t}(t_i - t_o)$$

where:

t_s = Inside surface temperature, °F

t_i = Inside air temperature, °F

t_o = Outside air temperature, °F

R_i = Resistance at the inside surface $= \frac{1}{f_i}$

R_t = Total resistance of the wall, floor, or ceiling $= \frac{1}{f_i} + \frac{1}{k_1} + \frac{1}{k_2} + \ldots + \frac{1}{f_o}$, in which

f_i = Inside surface coefficient $\left\{\begin{array}{l} \text{Walls } f_i = 1.65 \\ \text{Floor } f_i = 1.21 \\ \text{Ceiling } f_i = 1.95 \end{array}\right\}$ Btu per square foot per hour per degree F difference between inside and outside temperatures

f_i = Outside surface coefficient. For exterior walls with a wind blowing at a rate of 15 miles per hour the coefficient is 6.0. If the wall, floor, or ceiling is inside a building, the above appropriate coefficients for f_i may be used.

k = The number of Btu transmitted per square foot, per inch, per hour, per °F difference between inside and outside temperature.

Vapor Barriers

In rooms where walls separate spaces maintained at substantially different temperatures, vapor barriers should be provided on the warmer side of the walls to prevent a movement of water vapor into the insulated spaces that would eventually cause deterioration and impairment of the thermal insulation or of the wall construction by condensation. If a permeable surface were also provided on the colder side of such walls, it would permit escape of such water vapor as might leak into the wall despite the vapor barrier.

Papers impregnated or coated with asphalt that weigh 50 pounds per 500 square feet, papers surfaced with aluminum foil, and duplex papers known as 30-60-30 papers,† are usually found to be satisfactory vapor barriers‡. Three coats of aluminum paint over tight surfaces also provide a very good vapor barrier.

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* Heating, Ventilating, Air Conditioning Guide, 1948; Chap. 5, Fundamentals of heat transfer, pp. 97-110; Chap. 6, Heat transmission coefficients of building materials, pp. 111-139, illus.; ed. 26, 1280 pp., illus., Am. Soc. Heating and Ventilating Eng., New York.

† This paper consists of two sheets of kraft paper weighing 30 pounds per ream with a 60-pound layer of asphalt between them.

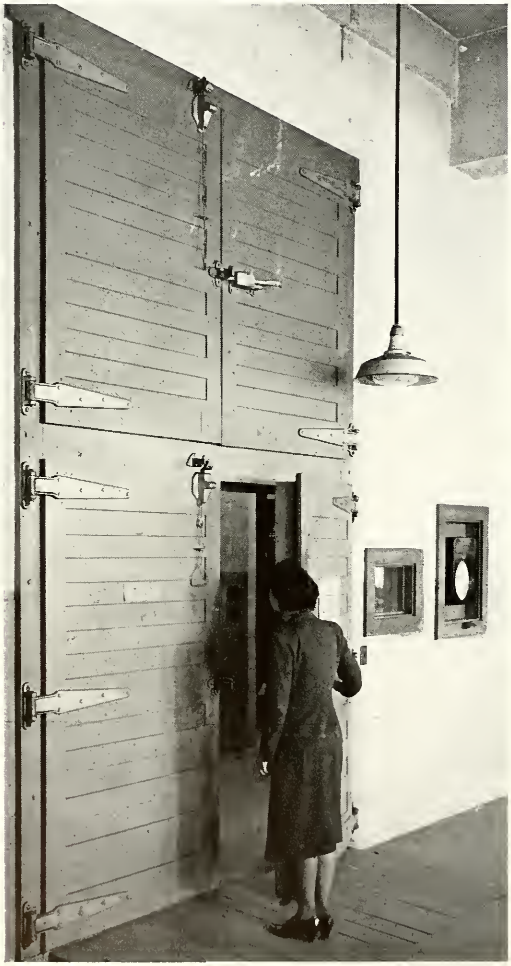
‡ Teesdale, L. V. 1942. Comparative Resistance of Vapor Transmission of Building Materials. Heating, Piping and Air Conditioning 14 (12) 736-742.

Doors and Entrances

Doors should be provided that are appropriate to the purpose of the room. They should, of course, be large enough to admit testing machines or other equipment that might be used inside the room. If such openings are large, a service door of moderate size should also be provided. A door of this type is shown in figure III.52. Doors should be so constructed as to maintain their shape and to provide sufficient thermal insulation, and should include vapor barriers and seals to prevent the infiltration of outside air or water vapor.

Vestibules are not ordinarily needed where passage in or out is occasional. Where very low temperatures are to be accurately maintained, a vestibule may be found desirable if the doors are used often. The vestibule should be large enough to enclose trucks that might be moved in or out of the room.

Figure III.52 This large door for temperature- and humidity-controlled room is designed for the admission of large testing machines. The bar between the upper and lower sets of doors is removable.



The large door shown in figure III.52 was designed to admit large testing equipment. It is made up of an upper and lower section with a removable bar between them. The lower right-hand door is used as an entrance for personnel. These doors are well insulated and have seals along the edges to prevent the leakage of air or water vapor. An instrument shown near the right-hand side of the illustration records on a circular chart variations in the temperature and relative humidity for a 7-day period.

Heat Losses or Gains

Where a room temperature is to be maintained above that of the surrounding space, heat must be supplied to replace that lost through walls, floors, and ceilings. A computation of the heat losses should be made[*], and from this calculation the required size of heating units may be determined.

Where a room temperature is to be maintained below that of the surrounding space, or a low humidity is to be maintained, provisions for cooling must be made. The cooling load should take into account thermal gains through walls, floor, and ceiling, and heat given off by electric motors, lights, burners, and appliances, and by the occupants[†] of the laboratory. If appreciable masses of warmer material are brought into the room, provisions should be made for reducing their temperature also.

When low humidities are used in the room, provision must be made for reducing the temperature of re-circulating air and water vapor and to remove the excess water produced by evaporation from stored materials, from persons working in the room, or from leakage of water vapor into the room.

Control Methods

For accurate temperature or humidity control, heating or cooling units should be designed carefully so that they will meet the requirements as closely as possible. If they are oversize, temperatures may surge beyond the intended control point because of the residual heat or of the cooling capacity of the units themselves. Heating or cooling units may be constructed in sections so that portions may be added to or taken out of service, depending on the conditions to be met.

Steam, warm water, or electric energy are frequently

[*] Heating, Ventilating, Air Conditioning Guide, 1948, Chap. 5, Fundamentals of heat transfer, pp. 97-110; Chap. 6, Heat transmission coefficients of building materials, pp., 111-139, illus.; ed. 26, 1280 pp., illus. Am. Soc. Heating and Ventilating Engin., New York. Close, P. D., 1946, Building Insulation: ed. 3, 372 pp., illus., Am. Tech. Soc., Chicago, Illinois. Shuman, L., 1948, Insulation, Where and How Much. U. S. Housing and Home Finance Agency, Washington, D. C., Tech. Bull. 3, 1-15, illus.

[†] Heating, Ventilating, Air Conditioning Guide, 1948, Chap. 12, Physiological principles, pp. 197-216, illus.; ed. 26, 1280 pp., illus. Am. Soc. Heating and Ventilating Eng., New York.

used for supplying heat to conditioning rooms. For large rooms, steam is probably the most available for use. For small rooms, however, warm water may be found more suitable for accurate control. Electric energy is ideal for small rooms or where electric power may be had at moderate cost. It is of great advantage because the resistance wires used in supplying heat have such a relatively low heat capacity that temperatures will not surge or materially rise above the desired control point after the power is cut off.

The cooling load may be carried by cold water if it can be supplied the year around, or when needed, at suitable temperatures, and this usually provides the lowest-cost form of cooling. Where such supplies are not present or the temperature of the water is not low enough, mechanical refrigeration may be substituted.

Water vapor for humidifying may be supplied in several ways: by air washers, by the discharge of steam into the space to be controlled, or by water sprays or combinations of water sprays broken up into a fine mist by low-pressure air. Water may also be mechanically distributed in space by discharging a fine stream of water against a plate, or by centrifugal force from a rapidly rotating disc or cone against a rim of small metal plates. If water supplies used in sprays contain minerals, each droplet evaporated will leave a residue or particle of dust that may be objectionable in some types of laboratories.

A very simple and easily controlled device for humidifying a small laboratory consists of a liquid-conductor heater. This device is a porcelain container with two perforated-plate electrodes set about 3/8 inch apart. When there is a deficit of water vapor in the space, electric energy is applied to the electrodes and the liquid between the electrodes acts as a resistance when a small amount of electrolyte is present, and quickly boils so as to release water vapor to the space.

Dehumidifying or the extraction of water from an enclosed space may be accomplished in one of three ways: condensation, absorption or adsorption. Condensation is the method used most commonly. It consists of passing an air stream through a cooling medium such as cold coils or water sprays. In this method the temperature of the air and water vapor passing through the sprays or coils is reduced to the dew-point temperature of the space to be conditioned. Water vapor condenses at the lower temperature, and thus any excess of that required for the conditioned space is removed. When the air and water vapor that have passed through the sprays or coils are reheated to the room temperature, the correct relative humidity will result.

Certain chemicals have the ability or property of absorbing water vapor from the atmosphere in appreciable quantities by absorption. Calcium chloride and lithium chloride are frequently used in air conditioning. There are many others, but these are the ones most frequently used. Calcium chloride is a rather inexpensive chemical and is not generally regenerated or dehydrated in order that it may be reused. When it absorbs a sufficient quantity of water, it changes from a solid to a liquid and is generally discarded. If, however, the desired relative humidity is high enough to use the calcium chloride as a solution, it may be reconcentrated by heating to remove excess water. This is always done when lithium chloride is used. When chemical sprays are used for air conditioning, very small drops of the solution are entrained in the air stream. The water soon evaporates and leaves a small particle of the chemical, which is deposited as a dust. This dust would be objectionable in many types of laboratories, and, if so, a very effective eliminator or filter should be inserted in the air stream to remove the small particles from the air delivered to the laboratory.

The physical structure of silica gel and of activated alumina makes them very satisfactory materials for removing excess water vapor from the atmosphere. These materials are extremely porous and adsorb water as an air stream is passed through a bed of either. When the silica gel or activated alumina has adsorbed enough water to change its vapor pressure and to reduce its ability to gather water vapor, the air stream is diverted to a second bed of the material and the one containing water is heated by oil or gas to drive off the water and thereby regenerate it. In some cases, three beds of the material are used, of which one is in use, a second is being regenerated, and a third is cooling off.

Dry air is supplied to conditioning rooms through this drier when the humidity in the controlled room becomes too great. A drier of this kind may be used to deliver dry air to several rooms if it is desired.

Mechanical Equipment

Air-conditioning equipment may be designed in a number of ways, depending on the conditions to be met and the convenience of operation desired.

Temperatures above or below those normally encountered may be easily controlled by a thermostat acting to control a heat or cooling source, as may be required. When a room is operated at an average room temperature, both heating and cooling means must be supplied with a thermostat to control the heat or refrigerant source.

When both temperature and humidity are to be controlled, the problem is a little more complicated and is generally accomplished by the use of an air washer. This equipment includes a circulating system in which the air is passed through a spray chamber and a cooling coil that either saturates the air by adding water vapor or removes some water vapor by condensation, as the conditions require. Heating the air and water vapor to the desired room temperature and supplying it to the room completes the process. It is sometimes found economical to recirculate all or part of the air supplied to the room by the conditioner, or it may be desirable not to recirculate any of it if there are a number of people working in the room.

For the sake of clarity, the accompanying drawings illustrating the operation of this equipment have been divided to show the air-circulation, water-circulation, refrigeration, temperature, and humidity control.

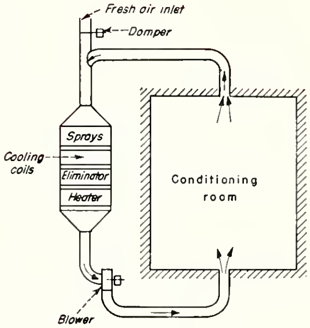
Figure III.53 illustrates the air-flow system. Air and water vapor are supplied to the room by a blower which draws the air from the conditioner. The diagram indicates a return duct and a fresh-air inlet by which all or part of the air from the room may be recirculated. The air stream passes through the sprays, cooling coils, and eliminator to the heater and into the room.

The essential parts of the water-circulating system are shown in figure III.54. The water is circulated through the sprays and is returned to the collecting tank from the coils and eliminators. During times when relative humidities are low, water is evaporated from the sprays and an automatic float-valve is provided to make up this deficit. A screen should be provided over the pump-line water connection in the collecting tank to remove particles of foreign matter that might clog the sprays.

The cooling system, shown in figure III.55, is composed of a refrigeration machine that supplies high-pressure liquid refrigerant to the cooling coils through an expansion valve. The compressor operation is controlled by an automatic switch in the high-pressure refrigerant line.

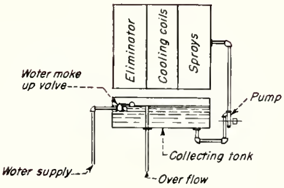
Two methods of providing relative-humidity control are indicated in figures III.56 and III.57. In one case the control is obtained by an insertion-thermostat in the collecting tank that controls the dew point, and in the other by a humidistat in the room. In both cases the supply of high-pressure liquid refrigerant to the cooling coil is controlled.

Two methods of temperature control are indicated in



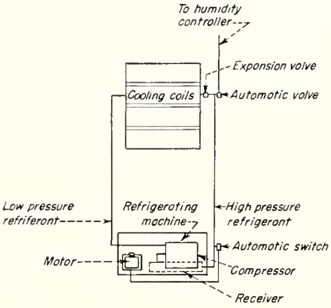
Air Flow Diagram

Figure III.53.



Water Circulating Diagram

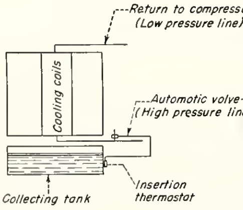
Figure III.54.



Cooling by Mechanical Refrigeration

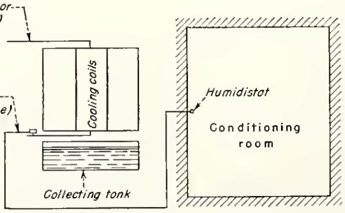
Figure III.55.

Figures III.53, 54, 55, 56, and 57 These diagrams show the general arrangement of parts of a temperature- and humidity-controlled room using mechanical refrigeration for cooling. Component parts are shown in separate sketches. Alternate methods of controlling the relative humidity are shown in figures III.56 and 57.


Return to compressor (Low pressure line)
Cooling coils
Automatic valve (High pressure line)
Collecting tank
Insertion thermostat

Humidity Control-Dew Point

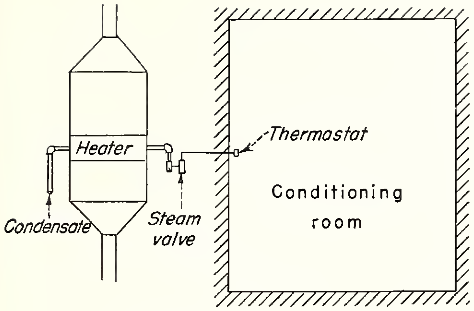
Figure III.56.



Humidity Control-Room Humidistat

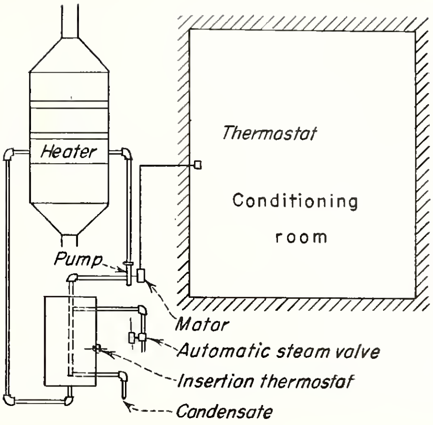
Figure III.57.

Note: See figure for heating system



Temperature Control-Steam

Figure III.58.



Temperature Control- Warm Water

Figure III.59.

Figures III.58 and 59 These two diagrams show alternate methods for controlling temperature that may be used with either refrigerant or cold-water systems of cooling.

figures III.58 and III.59. Steam or warm water is supplied to the heater, when required, by the action of a thermostat in the room. The warm-water system is more expensive to install than the direct steam radiation, but might be found more satisfactory than steam for small rooms.

The air-conditioning unit shown in figure III.60 is shown in a recess in a large testing laboratory at the Forest Products Laboratory. It contains cooling coils, water sprays, and a heater. Air is drawn through the sprays and heater into the duct system and is discharged at the center of the room ceiling. The air passing into the conditioner through the heating coil does not go through the condensing sprays and therefore is not cooled, and so it does not require reheating from the dew-point temperature. The air returns to the condensing unit through the grating near the bottom of the conditioner. The valves and dampers are operated by low-pressure air. Since several persons occupy the room, fresh air is introduced. The room is operated at a temperature of 70°F and 65% relative humidity the greater part of the time, but these conditions may be changed if testing requires.

The conditioning room shown in figure III.60 is supplied with refrigeration from the machine and asso-

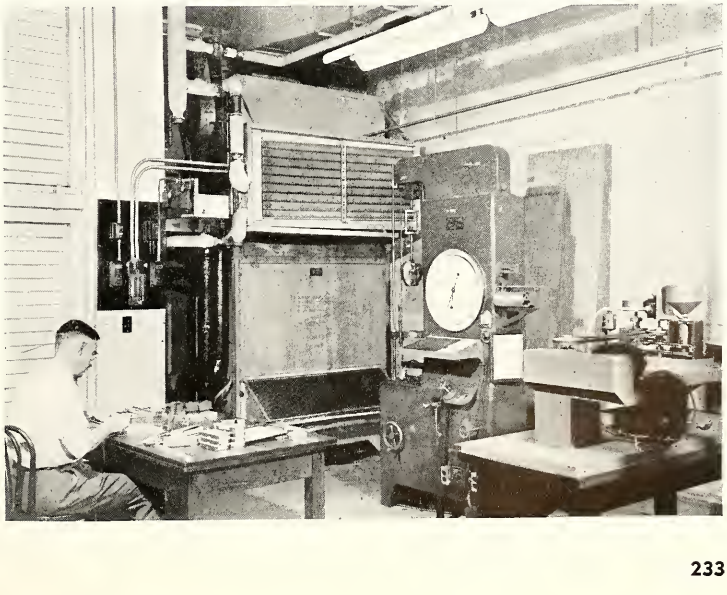


Figure III.60 This air-conditioning unit using mechanical refrigeration is located in a testing laboratory at the Forest Products Laboratory.

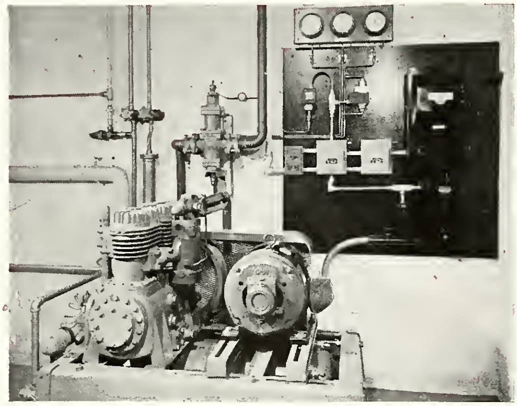


Figure III.61 This is the compressor supplying the refrigerant to the air-conditioning unit which is shown in figure III.60.

ciated control equipment illustrated in figure III.61. The machine uses dichlorodifluoromethane as a refrigerant, and the condenser uses city water for cooling purposes. In this case it is located on the floor below the conditioning room it serves.

When water is available from wells at a temperature below the dew-point temperature of the space to be conditioned, it may be used for maintaining the desired relative humidity.

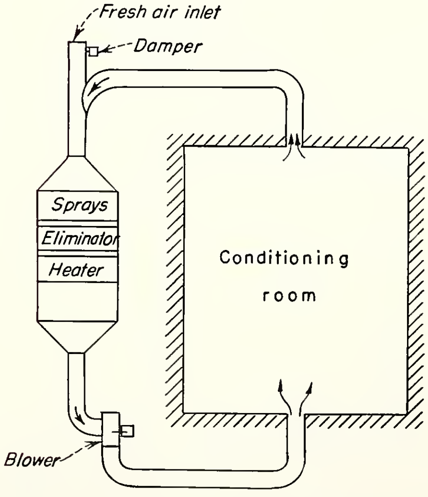
The general operation consists of passing an air stream through water sprays at the dew-point temperature. In so doing, the air is saturated at the dew-point temperature, and any excess water contained in the air stream is removed. The heater is used to raise the temperature of the air and water vapor to room temperature. The air-flow diagram is shown in figure III.62. It is similar to that shown in figure III.53, except that the cooling coil is not needed.

The water-circulating diagram is shown in figure III.63. Circulation is obtained with a pump that continuously sends the water through sprays and back to the collecting tank.

Temperature control for this system is the same as that given in figures III.58 and III.59. Steam heat would probably be found most economical for most installations, but warm water might be found advantageous for small rooms.

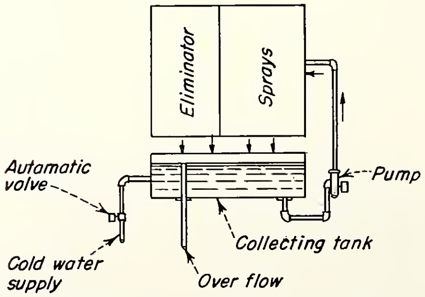
The relative-humidity control may be obtained by the regulation of the dew-point temperature, as shown in figure III.64, or by the use of a humidistat controlling a valve on the cold-water supply line, as shown in figure III.65. The humidistat in the room is perhaps a little more accurate, and the resulting relative humidity in the room would not be affected so greatly by temperature variations in the room.

Figures III.62, 63, 64 and 65 These diagrams illustrate the general equipment needed for temperature and humidity control where cold water can be obtained for cooling purposes.



Air Flow Diagram

Figure III.62.



Water Circulating Diagram

Figure III.63.

The arrangement shown in figure III.66 illustrates diagrammatically the equipment used for six temperature- and humidity-controlled rooms at the Forest Products Laboratory for conditioning wood samples. The diagram does not follow exactly the arrangement actually used, as the one shown includes improvements that appear desirable after 15 years of operation. Most important of these changes is the placing of the conditioning units outside of the rooms and the separation of the heating unit from the condensing unit.

This arrangement is suitable for controlling the conditions in a group of rooms designed very largely for conditioning purposes.

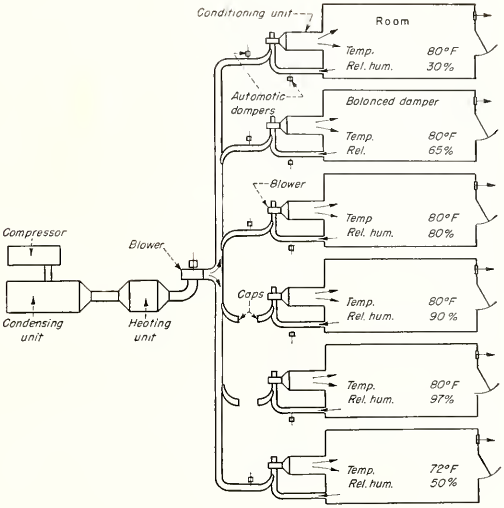
Each room is provided with a conditioning unit containing a heating coil, a cooling coil, an air-water spray for humidification, and a blower-type fan. A thermostat and humidistat that control the operation of valves and dampers with low-pressure air are parts of the equipment.

During the winter months when normal relative humidities within the building are low, the condensing unit is not operated; but during the warmer months when higher humidities exist, the unit is operated, and in this way dry air is admitted to the rooms to mix with the air therein and thus to reduce the relative humidity. A balance damper in the wall of the room permits the escape of air as dry air enters.

Dry-air supplies were not connected to the rooms maintained at 90% and 97% relative humidity, since relative humidities higher than these rarely occur inside of the building. However, the pipes were brought to the rooms and capped off in case they might be needed at a later time.

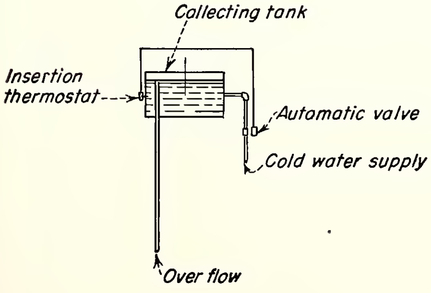
After a period of operation it was found that the coils were badly clogged with mineral deposits that had to be removed with acid. When the air-water sprays were operating, some of the water particles were carried back by eddy currents and the small mineral residues contained in solution in the water mist accumulated on the coils. From a maintenance view it would be better to use rain water or steam for such sprays.

The installation of conditioning units in the rooms has not been found satisfactory, particularly in the



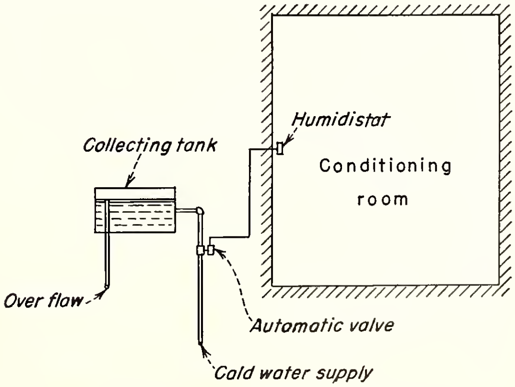
Air Flow Diagram

Figure III.66.



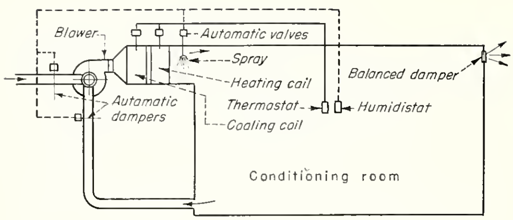
Humidity Control-Dew Point

Figure III.64.



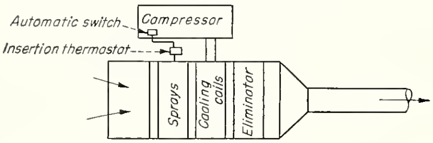
Humidity Control - Room Humidistat

Figure III.65.



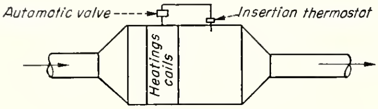
Air Conditioning Unit and Room

Figure III.67.



Condensing Unit

Figure III.68.



Heating Unit

Figure III.69.

Figures III.67, 68, and 69. General arrangement and mechanical parts of temperature and humidity rooms for conditioning and storage service. See figure III.66, previous page.

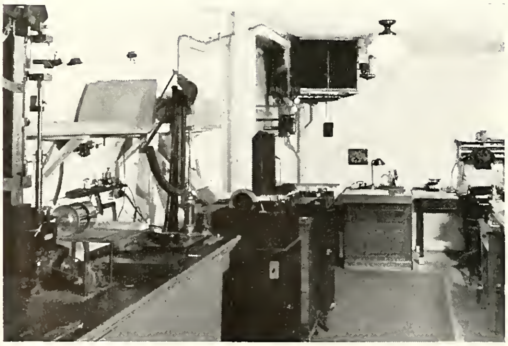


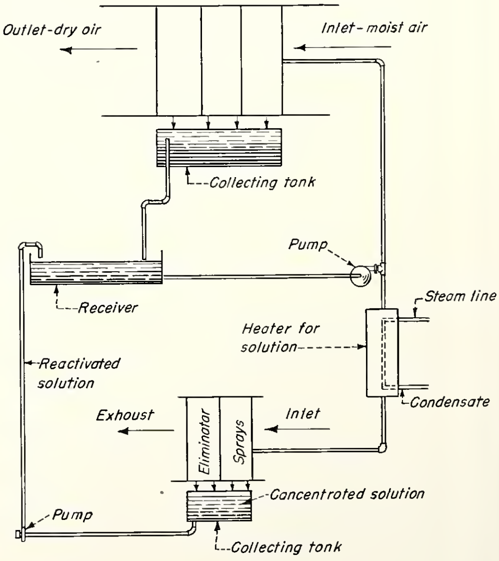
Figure III.70 This conditioning room, operated at 72° F and 50% relative humidity, is seen in the group shown in figure III.66, see previous page, at the Forest Products Laboratory for paper testing.

high-relative-humidity rooms. It was impossible to keep condensed water from dripping from the units, even though the pipes were well insulated. No trouble of this kind was experienced with the 30% and 65% relative-humidity rooms.

Figure III.67 illustrates the application of the unit to the room itself, with the temperature and humidity controls shown. The thermostat operates two automatic valves, one of which operates on low-pressure and the other on high-pressure air. In other words, when the steam valve is open, the valve controlling the cooling-water supply is closed. The humidistat operates two dampers and a spray valve. When the room requires dry air the spray valve is shut off, and the damper in the return line from the room to blower as well, but at other times the latter damper is open. The spray valve is open when the humidity becomes too low. The balanced damper permits the escape of air when dry air is being admitted to the room.

The condensing unit is shown diagrammatically in figure III.68. The sprays are kept at, or a little below, the lowest dew-point temperature required. The thermostat situated in the collecting tank below the sprays controls the operation of the compressor of the refrigerating machine.

The heating unit sketched in figure III.69 is intended



Dehumidification by Absorption

Figure III.71 General arrangement of a system of water-vapor removal by absorption.

to raise the temperature of the air from the condensing unit so that the temperature of the surface of the pipe will be warm enough to prevent condensation. The operation of the heating coils is controlled by the thermostat beyond the heating chamber. The heating coils should not be included in the condensing unit, since the demand for dry air is not continuous and the heating coil would work against the cooling coil.

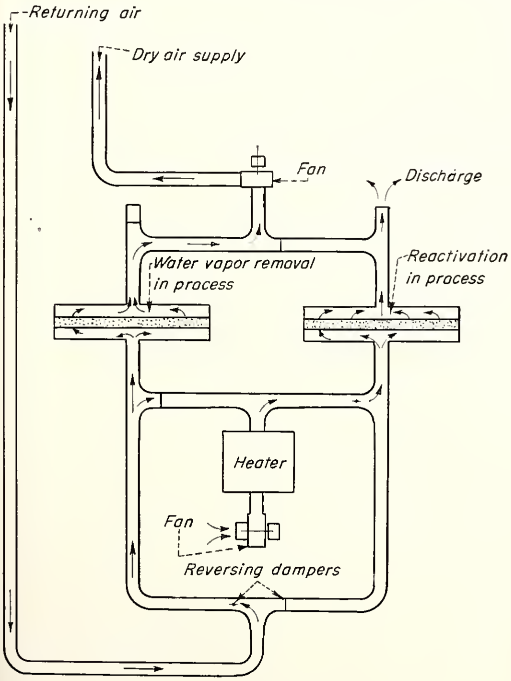
Figure III.70 is a photograph taken in the paper-testing laboratory of the Forest Products Laboratory. It illustrates the use of a conditioning unit within the room where a temperature of 72°F and 50% relative humidity is maintained. The unit contains a cooling coil, a heating coil, a low-pressure air-water spray, and a disc circulating fan. The cooling effect is obtained from city water that is available at 55°F. Dry air, when required, is supplied from a central condensing unit serving several other rooms as well. The controls consist of a thermostat and a humidistat. The control valves and dampers are operated by low-pressure air.

The diagrams shown in figures III.71 and III.72 illustrate two methods of providing dry air for individual rooms or for a group of rooms shown in figure III.66. In this case either one would take the place of the condensing unit and compressor.

Water vapor may be extracted from air supplied to a controlled room by the use of a chemical solution, such as lithium chloride, having a vapor pressure less than that required in the room itself. Water vapor coming in contact with this solution is absorbed by it (see figure III.71). The solution is sprayed in the air stream leading to the conditioned space and is returned to a collecting tank and receiver from which it is pumped to the sprays and to a heated tank. The portion passing through the heater is sprayed hot in a stream of air, and thus some water vapor is removed in the exhaust and the solution is concentrated. The solution is returned to the receiver for reuse. The cooling coils remove the heat of absorption and sensible heat from the air stream.

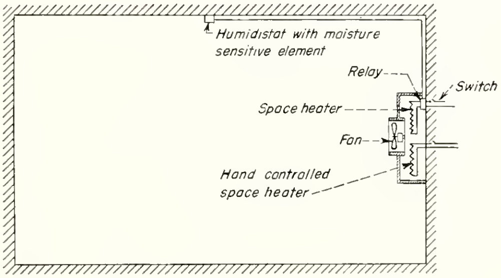
The use of adsorbing materials, such as silica gel or activated alumina, is illustrated in figure III.72. The system comprises two or more beds of the adsorbing agent, one of which is arranged to remove water vapor from the air while the other is being reactivated by the passage of gases at a temperature of from 300° to 600°F. The air flow to the conditioning room is through the left-hand bed. Dampers are arranged for reversing when the vapor pressure of the adsorbing bed becomes too high and no longer extracts sufficient water from the air stream.

The diagrams of figures III.73 and III.74 illustrate a



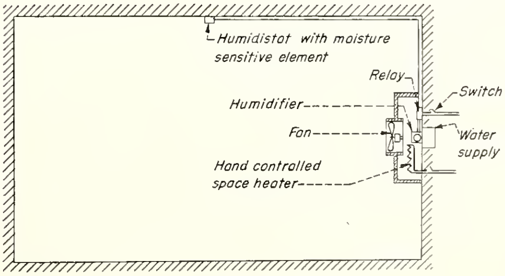
Dehumidification by Adsorption

Figure III.72 General arrangement of a system of water-vapor removal by adsorption.


Humidistat with moisture sensitive element
Relay
Switch
Space heater
Fan
Hand controlled space heater

Moisture Content Control by Temperature Regulation

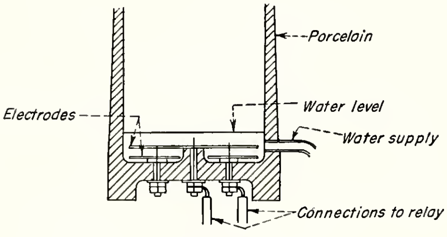
Figure III.73 This sketch shows a method of controlling the moisture content of materials by temperature control.


Humidistat with moisture sensitive element
Relay
Switch
Humidifier
Fan
Water supply
Hand controlled space heater

Moisture Content Control by Humidification

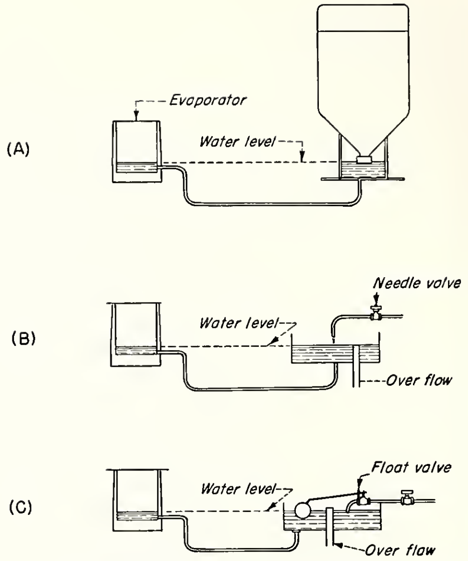
Figure III.74 The sketch illustrates a method of regulating the moisture content of stored materials by humidity control.

Figures III.75 and 76 These diagrams illustrate a method of supplying water vapor to a conditioned room using a liquid-conductor evaporator.



Liquid Conductor Evaporator

Figure III.75.



Water Supplies for Liquid Conductor Evaporators

Figure III.76.

low-cost arrangement for providing conditioning space for materials being brought to a constant-moisture content or that are stored to maintain constant moisture-equilibrium conditions.

Where moisture-content control is desired for conditioning hygroscopic materials, the relative-humidity or equilibrium-moisture-content conditions may be controlled by raising the temperature of an enclosed space. Because the absolute humidity is held constant, or increased a limited amount, an increase in temperature decreases the relative humidity by virtue of the greater water-vapor-holding capacity at a higher temperature. The use of this system depends on the condition that the relative humidity in the space to be conditioned is greater than that needed. In some cases moisture evaporated from stored material will provide the higher-relative-humidity condition if it does not exist. It is possible to evaporate a limited amount of water in the space to cause the temperature controller to operate on the above basis.

The equipment needed is shown in figure III.73. It consists of a humidistat operated by a hygroscopic element that controls a heating coil shown as an electric space heater, but it may be a steam or warm-water coil if either is thought more suitable. A hand-controlled source of heating energy is also indicated, which may be used to supply an insufficient amount of heat. The controlled heat source is arranged to make up the deficiency not met by the hand-controlled heat source.

A circulating fan is indicated at the top of a housing, with an inlet at the floor level to keep the air in motion and to produce the same relative humidity throughout the room.

Moisture-content-control rooms may be regulated by a moisture-sensitive element attached to a humidifier, provided the existing relative humidity is lower than that required in the conditioned space, as shown in figure III.74. If the relative humidity is above the desired regulating point, it may be lowered by increasing the temperature of the room with a hand-controlled space heater.

The air and water vapor in the conditioning room are recirculated through an enclosure that is open at the bottom, with a disc fan near the ceiling of the room.

The liquid conductor heater shown in figure III.75 has been found very useful for humidifying small, tight rooms. It consists of a porcelain jar containing two circular electrodes near the bottom. Water containing a small amount of electrolyte is kept at a level just above the top electrode. When water vapor is needed in the room, electric power is applied through a relay. The water acts as a resistance and soon boils and evaporates water vapor into the enclosed space. The evaporation ceases as soon as the power is cut off. The humidity controller should operate through a relay to switch the electric energy on and off. In case of a water failure, the connection between the electrodes is broken and the electric power is cut off.

If the available water source contains minerals, they gradually collect on the electrodes and foul them so that they may become inoperative after a time. Distilled water or rain water are preferable for use in liquid conductor heaters, since they do not contain residual matter. It is necessary to add a weak salt solution to serve as an electrolyte in the heater. Very little of this solution is required and it should be added very slowly with a medicine dropper. Once it has been added it will remain indefinitely without additions.

Figure III.76 illustrates three ways of keeping water in a liquid-conductor heater at a constant level. The first arrangement, shown in sketch A, provides the water supply by means of an inverted bottle. When the water level drops, air is admitted to the bottle, from which water is released to reestablish the proper water level. The tube connecting the liquid-conductor heater and the bottle support should be below the required water level.

The arrangement shown in sketch B allows water to drip into a receiver at a little greater rate than that at which it is evaporated, with an overflow at the proper level.

Sketch C shows a float-valve arrangement for maintaining a constant water level.

Temperature Controls

There are a variety of temperature regulators commercially available. Bimetallic elements, consisting of two metals having different coefficients of thermal expansion intimately joined together, are extensively used. Changes in temperature cause them to deflect, which makes it possible for them to open and close airports or to make and break electrical contacts.

The difference in direct thermal expansion between two metals is also used with the aid of lever arrangements to augment the small amount of movement of the two metals.

The expansion of a gas or a liquid enclosed in a bulb and connected through capillary tubing to a Bourdon tube is also extensively used. The Bourdon tube is a curved tube of small diameter that is deflected by pressure changes and so operates controls. This type of equipment is of advantage in that the temperature-sensitive bulb can be placed at some distance from the operating parts.

Humidity Controls

Humidity is controlled by several types of instruments. Temperature controls may be adapted to this use by placing the temperature-sensitive element in the water lines leading to sprays, or in tanks supplying the sprays. When used in this way, the dew-point temperature is controlled. Water vapor carried in the air stream, beyond that needed in the space, is extracted by contact with the cold spray, or water vapor is added as may be required to maintain the desired humidity.

If a wick, placed over the temperature-sensitive element of a thermostat, is supplied with water and placed in the flow of an air stream to a humidified space, or within the space itself, wet-bulb control is obtained. Heat is required to evaporate water, and, as it does, the temperature of the thermostat element is reduced to the wet-bulb temperature. The air flow over such instruments should be very rapid to obtain the maximum wet-bulb depression. The wet-bulb depression, or the difference between the air temperature and the wet-bulb temperature, varies with the relative humidity, so that it may be used for control purposes in conjunction with a thermostat controlling the air temperature of the conditioned space.

Wet-bulb controllers may be used to regulate the temperature of cooling coils or sprays or can be made to operate steam jets or water sprays discharging directly into the humidified space.

Hygroscopic materials that shrink and swell with changing atmospheric conditions, have been employed extensively as humidity controllers. Such materials are mounted in such a way that a small amount of shrinkage or swelling operates air or electric circuits to produce the conditions needed.

Materials extensively used for the purpose are hair, goldbeater's skin, or a column of thin end-grain wood. A number of strands of human hair with the natural oils extracted is usually mounted in end supports attached to a lever system. Goldbeater's skin is a very thin membrane obtained from the intestines of cattle. It is quite strong in tension, and may be mounted in tension for control purposes.

Thin strips of wood cut across the grain provide another means of controlling relative humidity and are sometimes used in tension, but more frequently in compression. Elements of this kind are occasionally used to operate valves directly.

Hair or goldbeater's skin is very sensitive to changes in relative humidity and responds quite rapidly. Thin strips of cross-grain wood require more time to secure proper adjustment than hair or goldbeater's skin, but correct variations from the desired control-point quite well.

Hygroscopic materials used as controllers serve very well when variations from the desired setting are not great, but may require readjustments if the conditions vary accidentally over a wide range.

Recording Instruments

A continuous record of the operation of a conditioning room is very desirable, and a number of instruments are available for this purpose. Charts afford a permanent record, assist in locating trouble and indicate the degree of operational accuracy obtained.

All actuating elements mentioned for temperature and humidity control are suitable for recording instruments, except strips of wood cut across the grain, which are too slow in action if changes take place rapidly. When wet- and dry-bulb temperature recorders are used, the relative humidity must be obtained from a separate chart. The instruments employing a hygroscopic element for recording relative humidity read directly.

Automatic Valve-operating Arrangements

In order to keep a conditioned room under proper control, adjustments must be made in the supply of of heat, refrigeration, water vapor, or air. Low-pressure air is used to actuate valves and is so arranged that it produces pressure over diaphragms to open or close the valves. This operation is accomplished by opening or closing a very small port and allowing the pressure to build up or be released. Air-operated instruments are designed for throttling purposes, so that a valve can be partially opened and thereby make small adjustments.

Electric systems are also available for operating valves, dampers, and switches. Thermostats or humidistats make electric contact to correct a condition leading away from the desired control point. The electric energy used in such circuits usually carries only a few milliamperes of current so as to avoid arcing at the contact points. The low-energy electric current actuates a relay that switches in the appropriate amount of energy to operate solenoid- or motor-operated valves, dampers, or switches.

Pipe Covering

All tanks, air washers, or pipes carrying air, low-temperature water, or refrigerants, whose surface temperatures are likely to be below the dew-point temperature of the atmosphere in which they are situated, should be adequately covered to prevent condensation. Materials used for covering cold surfaces should be resistant to the transmission of water vapor and, where fibrous materials are used, a high-quality vapor barrier should be applied over the insulation to prevent the entrance of water vapor.

9

HIGH-PRESSURE LABORATORIES

R. L. Savage *

Battelle Memorial Institute, Columbus, Ohio

Research on the physical properties and chemical activity of gases, solids, and liquids at high pressures has been in progress for many years. The recent introduction of new commercial processes operating at very high pressures has served not only as an index of the successful application of the results of this research but also as a stimulus for much more activity in this field. Pressures used experimentally have ranged from a few hundred to over one million pounds per square inch†, depending on the type of program being pursued. This chapter is concerned principally with the pressure range from a few thousand to about sixty thousand pounds/square inch although much of the information is applicable at both lower and higher pressures.

There are many useful references in the literature, including several important books. The work by Bridgman‡ and by Bassett** has led to the development of techniques for attaining extremely high pressures. Their work has related chiefly to the physical, rather than the chemical, properties of material at high pressures. In the study of chemical reactions under pressure, a much greater variety of work has been done, both in Europe and in North America. It is this part of high-pressure research that is undergoing the greatest expansion. Books by Tongue§ and Newitt§§ discuss both laboratory and plant operation. This information is supplemented in more recent articles. Despite the obstacles of the relatively high cost, the many mechanical problems, the care required in assembling and operating high-pressure equipment, and the need for stressing personnel safety, increased activity in the field is indicated by: 1. an expansion in the equipment and activities of laboratories already equipped to do this type of research, 2. the addition of high-pressure facilities to those already available in research laboratories, and 3. the building of new high-pressure laboratories.

Realization of the potential hazards of operating high-pressure equipment has resulted, in most cases, in the use of protective measures. However, there are laboratories, particularly in universities, but also in some industrial establishments, in which high-pressure equipment is being used without proper protective barricades. Bitter experience has shown the need for adequate protection for the operating personnel and the added initial cost is well justified. Moreover, in laboratories where proper facilities are utilized, long periods of safe operation have been realized.

LOCATION OF THE HIGH-PRESSURE LABORATORY

Protection for other personnel in the plant or laboratory as well as for the operators indicates that the high-pressure laboratory buildings should be isolated from other activities. Because of the projectile action of ruptured vessels, some industrial research laboratories have arranged their high-pressure laboratories to face an open field or wooded area, some over a sizeable body of water, and others at a suitable distance from the side of a hill or embankment. The latter two locations are preferable since there is less chance of injury to persons or property not a part of the laboratory.

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* Present location: Case Institute of Technology, Cleveland, Ohio.

† Bridgman, P. W., "Recent Work in the Field of High Pressures," Rev. Mod. Phys. 18, 1-93 (1946).

‡ Bridgman, P. W., "The Physics of High Pressure" (G. Bell and Sons, London, 1931).

** Basset, J., "Production and Measurement of Very High Pressures," Chimie et industrie 53, 303-310 (1945).

§ Tongue, H., "The Design and Construction of High-Pressure Chemical Plants" (Chapman & Hall, Ltd., London, 1934).

§§ Newitt, D. M., "The Design of High Pressure Plant and the Properties of Fluids at High Pressures" (Clarendon Press, Oxford, 1940).

If space or other limitations prevent the construction of a separate high-pressure laboratory building, then the most isolated location available, such as the corner or end of a building, should be utilized. Basement areas are not well suited for high-pressure laboratory space because, generally, there is not enough window space available for pressure relief in case of an explosion. A large open area, large window areas, or light panel walls should be located opposite the high-pressure areas to provide pressure relief from equipment failure or from an explosion resulting from an accumulation of gases around a leak in the apparatus. This is best done in a single-story structure with the protective barriers extending up to or through the roof, but several modifications have been used and adapted to specific locations.

SIZE OF HIGH-PRESSURE LABORATORIES

Besides the space for the high-pressure equipment, there must be provisions for machine shop facilities for setting up and maintaining high-pressure apparatus; laboratory space for the preparation of catalysts and reactants, for examination of products, and for cleaning, charging, and unloading the pressure vessels, preferably in a well-ventilated area; office space for the technical and supervisory personnel; and storage space. The availability of these facilities in other parts of the laboratory will determine whether it is necessary to include them as part of the high-pressure laboratory but in most cases it is desirable from the standpoint of efficiency to have them as an integral part of the high-pressure facilities.

Considering only the space needed for the high-pressure equipment, the size of a laboratory may vary from the space needed for only one autoclave to that needed for several autoclaves of varying sizes plus space for batch and continuous units of laboratory and pilot-plant size. As is the case for most research operations, the initial space available is generally too small after a few years of operation of the laboratory. Therefore, some provision for expansion should be included in the original building. If the laboratory is properly isolated, this problem is minimized.

The minimum floor space inside a barricade for a standard type of rocking autoclave may be arbitrarily set as 3'6" by 6'0". However, since it is preferred to have not less than 3 feet of free space around the rocker, the floor space should be 8'0" by 9'0".

It is best to have 3-foot aisle separating each autoclave barricade but most laboratories realize some saving in floor space by having one aisle between every second barricade so that it is possible to enter the hazardous area from only one side. For most types of operations this is satisfactory. The barriers themselves should be not less than 10 feet high. From information on the floor space needed for the high-pressure reactors, pumps, and compressors, and the space for auxiliary services, an initial estimate of the size of the laboratory may be made.

PLANS FOR HIGH-PRESSURE LABORATORIES

Although the possible arrangements of floor plans of high-pressure laboratories are numerous, the practical consideration of arranging the pressure equipment to blow out over an isolated area generally has led to the adoption of rectangular floor plans. The pressure equipment is located along one side of the building with a center aisle separating the barricades from the laboratories, offices, and work areas.

Two industrial laboratories may be cited as examples of this type of construction. In both cases the high-pressure laboratories are in buildings separate from the rest of the research facilities. Figure III.77 shows the floor plan of the small high-pressure laboratory at the Goodrich Research Center near Brecksville, Ohio. There are four individual pressure areas, all facing an open field. There is the possibility of dividing the two larger areas into smaller booths in the future. The overall dimensions of the building are 20'0" by 50'0", which provides for only a minimum of auxiliary bench space along the wall opposite the barriers. The laboratories, work shop, and offices for the high-pressure laboratory personnel are in the main research building nearby.

At the new research center of the Carbide and Carbon Chemicals Corporation in South Charleston, West Virginia, the high-pressure laboratory is considerably larger and is practically a self-contained research unit. The building shown in figure III.78 provides space for six small pressure areas for autoclave work, two larger areas for continuous high-pressure units, and one large area with extra high barriers for pilot plant work. The open side of these pressure areas faces a hillside about 35 feet away. The work rooms, laboratories, and offices are separated from the pressure barricades by a 10-foot aisle.

Both of these laboratories were designed and built for high-pressure work. In situations where it is necessary to utilize space already provided it is still possible to incorporate many of the desirable features of the above designs. Although basement areas are not recommended, the high-pressure equipment at Case Institute of Technology has been placed in two reinforced concrete ш-shaped barricades with the open side facing a concrete wall below ground level. This is permissible because the chemical engineering laboratory in this part of the building has an open space up through two stories and the large window area above ground allows for pressure relief. The chief danger in an installation of this type is from flying fragments of ruptured pressure vessels ricocheting back into the working area. The high-pressure laboratories at Northwestern University and at the Stamford, Connecticut, laboratory of the American Cyanamid Company rely principally on totally enclosed steel barriers around the autoclaves with working areas all around them. With proper reinforcement (sand between steel plates is used at Stamford) to stop the projectile action of ruptured vessels, and proper ventilating to avoid the build-up of explosive mixtures from leakage of flammable gases, this arrangement may be made acceptable. A major problem in designs of this type is to provide enough space for release of the large volumes of gases that may be formed in an explosion.

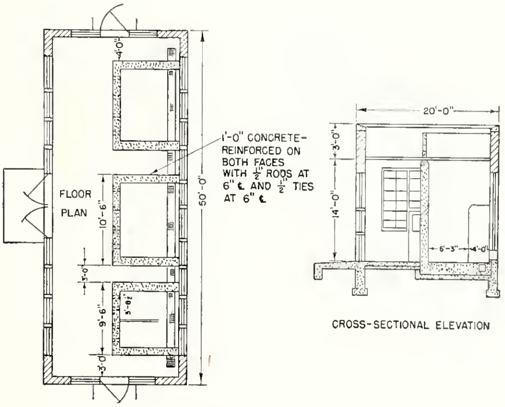
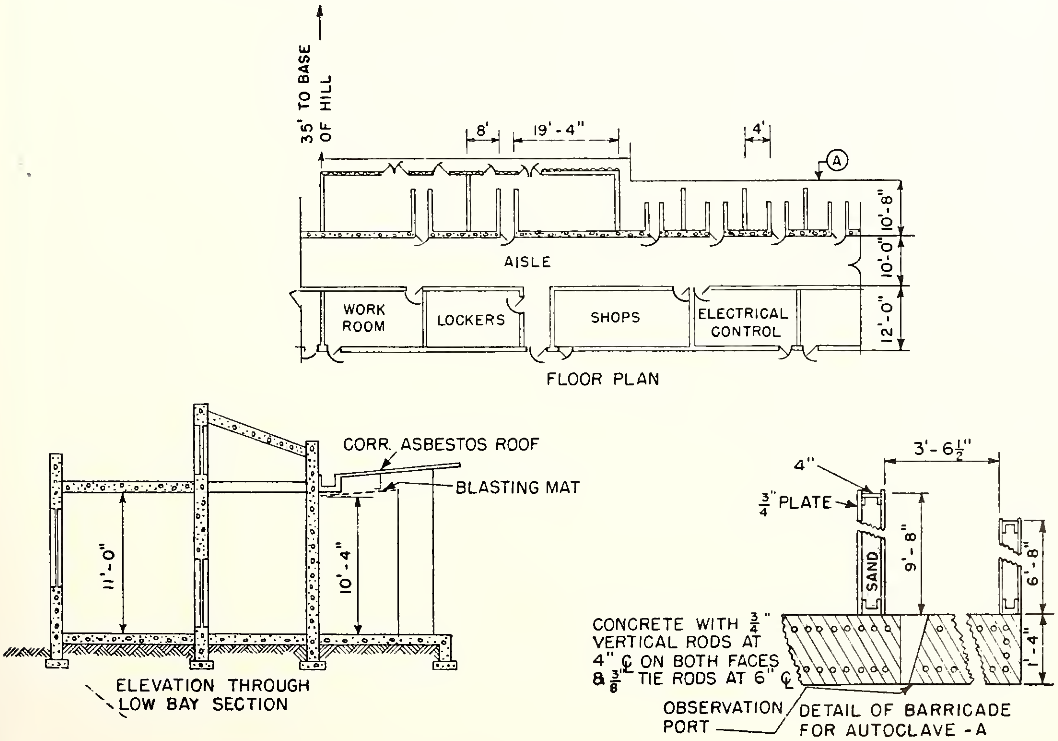

FLOOR PLAN
4'-0"
10'-6"
3'-0"
9'-6"
3'-0"
50'-0"
1'-0" CONCRETE-REINFORCED ON BOTH FACES WITH ½" RODS AT 6" ℄ AND ½" TIES AT 6" ℄
20'-0"
3'-0"
14'-0"
6'-3"
4'-0"
CROSS-SECTIONAL ELEVATION

Figure III.77 High-Pressure Building—B. F. Goodrich Research Center.

CONSTRUCTION OF PRESSURE BARRICADES

Consideration of the potential hazards in the operation of high-pressure equipment and of the experience of established laboratories will determine the requirements for the barricades. The principal danger is from the projectile action of the equipment or fragments of it, and consequently the protective wall must be able to absorb and dissipate the force of the fragment. Reports* have shown that the human body may survive the pressure effects from a blast pressure of 400 psi but that only one psi pressure is required to hurl a person

Figure III.78 High-Pressure Research Design—Carbide and Carbon Chemicals Corporation.



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* Field, C., "Dead Men Do Tell Tales," Chem. Eng. 54, No. 3, 118 (1947).

about. Most of the casualties occur by the body being thrown against solid objects or by high-velocity fragments.

For a temporary installation of pressure equipment, the use of sand bags is economical and will give good protection. Since sand bags are not well suited for permanent installations, several other types of barriers have been devised. Blasting mats are useful for both temporary and semipermanent installations.

The trend is toward the use of reinforced concrete barriers although this is not universal. Modifications of specifications for shell loading areas and for bomb shelters designed to withstand the direct hit of a 500-pound demolition bomb have been used in some laboratories.

The concrete walls for the Carbide and Carbon Chemicals Corporation high-pressure area are reinforced with ¾-inch vertical and horizontal steel rods spaced every 4 inches on both faces of the 16-inch-thick wall (figure III.78). Lateral reinforcement is with ⅜-inch rods spaced 12 inches apart. In the Goodrich laboratory, the 12-inch concrete barricades are reinforced with ½-inch rods every 6 inches on both faces. This barricade is set on a 3-foot-thick floor slab and is made an integral part of it by bending the bottom vertical reinforcing rods into the horizontal slab (figure III.77).

While reinforced concrete is a very safe type of construction, the added floor space used and the difficulties in mounting equipment and supplying service outlets have led many laboratories to prefer steel barriers, or combinations of reinforced concrete and steel. Many modifications in design using steel panels are possible and are in use. The minimum thickness of plate for protection of the operators is 3/16 to ¼ inch. Some men experienced in the field feel that such barriers offer no more than psychological protection and there is considerable evidence to indicate that some of the more violent explosions of high-pressure equipment would have ruptured ¼-inch steel plate.* It has been observed that such plates do offer a fair degree of protection for small equipment operating at pressures up to 5000 psi and certainly are much better than no barriers or those of brick and masonry construction.

The sandwich type of construction, with timber or sand as the filler between steel panels, is to be preferred over steel alone. There are arguments in favor of and against both timber and sand, the chief one against wood being the possibility of splinters. With ¼- to ¾-inch plates on both sides of the wood, the chance of a fragment going through both plates and carrying splinters with it is rather small. The objection to sand is in the possibility of its leaking out if holes are drilled into the barrier to mount equipment or provide services.

Two important factors must be considered in erecting steel barriers. The first is the method of fastening the barrier to the floor. It is doubtful that simple bolting of the panel to a concrete floor with expansion bolts would prevent the whole barrier from being pushed over by a major explosion. Consequently, the panels should be fastened to angle irons or structural pieces that are an integral part of the building or that are imbedded in the concrete floor.

The second factor, which applies especially to single steel panel construction, deals with the method of fastening the steel plate to the supporting structure. The plate should be placed on the pressure side of the supporting structure when it is bolted or riveted into place so that the force of an explosion will not be carried solely by the bolts, rivets, or welds but by the whole structure (figure III.78).

The panels should be extended to a height of at least 10 feet and should preferably be extended to or through the ceiling of a one-story structure. If they are below ceiling height, a blasting mat of steel cable should be placed over the top to stop flying fragments. Observation of the gauges and equipment may be provided for by the use of mirrors or observation ports. The Goodrich laboratory has 3" by 6" observation ports extending upward at an angle of 45° from the horizontal through the reinforced concrete so that the mirrors can be seen. In the Carbide and Carbon Chemicals Corporation laboratory, two vertical observation ports are provided for each pressure area. These are 2 inches wide and are covered with safety glass on the outside; they spread to a width of 4 inches at the inside of the reinforced concrete barricade.

HIGH-PRESSURE EQUIPMENT

High-pressure fittings and equipment for typical applications have been standardized to some extent and are available from various suppliers.† Some of these units will be described to illustrate what is available and in use. In addition, many special reactors and fittings for special investigations have been described in the literature.

The most important precaution concerning high-pressure fittings and equipment is that makeshift fittings and vessels should not be used. Pipe thread connections are not recommended because of the danger of weakening the threads when tightening the joint enough to prevent leaks. If it is necessary to use a pipe thread under pressure, the joint should be tightened in the usual manner to provide mechanical strength and then sealed by soldering or brazing around the thread. The cast fittings for standard pipe are particularly unsafe above their rated pressures because of the possibility of defective castings. Extra strong and double extra strong forged fittings may be used at their rated pressure as auxiliary equipment.‡

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* Bolt, R. O., and Joyce, R. M., "Laboratory Explosions with Ethylene and Carbon Tetrachloride," Chem. Eng. News 25, 1866 (1947).

† American Instrument Company, "Superpressure Apparatus, Catalog 406," Silver Spring, Md.
Autoclave Engineers, Inc., "High Pressure Autoclaves, Catalog 100," Chicago, Ill.

‡ Perry, J. H., "Chemical Engineers Handbook," p. 903 (McGraw-Hill Book Company, New York, 1941).

The conical fitting for high-pressure tubing has been widely adopted for the small sizes that are used in experimental work. With reasonable care in tightening, the tubing joints may be used many times before refacing is necessary. The conical ends and the threads are best formed in a lathe, but special hand tools for this purpose are available for use in the laboratory. Figure III.79 shows how these high-pressure connections are made. No gaskets are required with this type of connection. A widely used modification utilizes a copper gasket to form the seal between a flat end of the tubing and the body of the fitting, the lefthand threaded sleeve and threaded nut being the same as for the conical tubing. Gaskets must be replaced frequently because the copper tends to flow under compression. High-pressure tubing and a wide selection of fittings and adapters are available.

Block-type needle valves are generally used for both shut-off and bleeder valves. For pressure service up to 25,000 psi, standard packing and integral valve stems are used. For pressure service in the range from 30,000 to 60,000 psi, the American Instrument Company and Autoclave Engineers, Inc., have special packing designs for effecting seals. Both companies are offering a valve design incorporating a thrust bearing on the valve stem for operating at 100,000 psi. The design for one of these is shown in figure III.80.

Relief and safety valves are available over wide pressure ranges either as rupture diaphragms or pop-type valves. Considerable difficulty is often encountered in reseating the spring-loaded type. Although better protection is obtained through the use of blow-out disc assemblies, they have the disadvantage that the entire contents of the vessel are exhausted. Two other factors must be considered in the use of blow-out discs. Corrosion may weaken the disc and cause failures during operation below the rated blow-out pressure or work hardening of the disc may occur to prevent its operation at the rated pressure. Therefore, frequent inspection and replacement of the discs are necessary. The first disadvantage may be circumvented by the use of a disc and safety valve in series, the disc to provide a positive seal and the safety valve to shut off the flow of gases when the pressure has been reduced to the operating range. Several formulae have been given* to calculate the bursting strength of discs from various metals but their value is still somewhat questionable and standard practice seems to be to cut several discs from a sheet of stock metal for calibration purposes. Preforming of the disc may be necessary for reproducible results.†

For either type of protective device, it is essential to have the relief valve or blow-out disc located so as to minimize the chance of plugging the line leading to it. In any case, these protective devices are effective only for moderate rates of pressure build-up, such as from overheating, and will offer no protection of the equipment from an explosive reaction or a detonation; therefore, pressure barriers must be used.

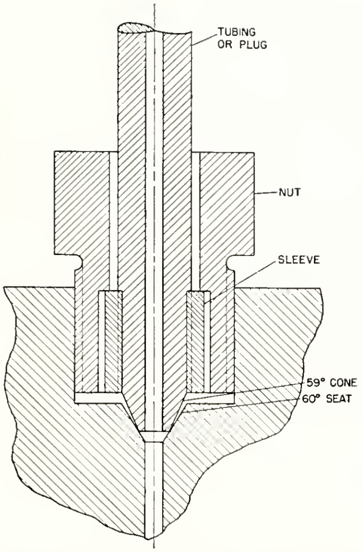
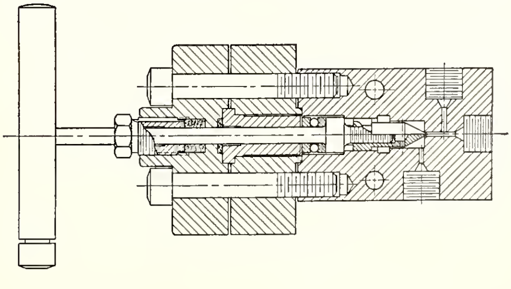


Figure III.79 Super-pressure Coupling—American Instrument Company.

Pressure vessels range in size from a few milliliters to many gallons. The normal sequence of high-pressure development is to start with the small reactors and to carry out the reaction in successively larger reactors. Microbombs are not only safer for new reactions but are more efficient for investigating a range of catalyst and operating conditions because several microbombs can be cleaned, loaded and charged by an operator in the time that it takes to complete the same operations with a 2- or 3-liter autoclave.

Both the small and large reactors are agitated by rocking in a heated jacket but stirring types also may

Figure III.80 100,000 P. S. I Valve—American Instrument Company.



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* Murphy, T. S., "Rupture Diaphragms," Chem. Met. Eng. 51, No. 11, 108-112 (1944).

† Huff, C. E., "Weak Spots for Protecting High Pressure Vessels," Chem. Met. Eng. 51, No. 12, 99 (1937).

be had. Stirring autoclaves ranging from one liter to 20 gallons in size are available[*] as standard vessels and may be equipped for either top- or bottom-entering agitators. The selection of a suitable design and material for a high-pressure stuffing box around the rotating shaft is a serious problem. At present, water-jacketed stuffing boxes are used with an inner packing of all-metal ring type, a lantern ring and an outer packing. Lubrication and an oil seal at the lantern ring are provided from a high-pressure oil reservoir which may be connected to the reaction vessel or to an external source of pressure. Mechanical packing sets are being supplied on some one-liter glass-lined autoclaves[†] for pressures up to 1000 psi. Packings may be eliminated entirely by the use of induction stirring. The Standard Oil Company (Indiana) design for magnetic stirring is available for use at pressures up to 15,000 psi.[‡]

The design of high-pressure vessels is rather complex and requires a consideration of the many factors that may be encountered during the service of the vessel. Worthington[**] gives a chart showing the results of several design formulae and this work has been extended by Boe[§] who reduces the results of the various formulae to a common basis of comparison. Multi-layer construction is advantageous for larger vessels and the application of these formulae to this type of construction was discussed by Jasper.[§§]

Although the number of investigators who may choose or need to design vessels is small, the information is of considerable importance to engineers who are responsible for or who are handling high-pressure equipment because of its relationship to the testing of vessels. An arbitrary test for a pressure vessel consists of subjecting it to a hydrostatic pressure of 1.5 to 2 times its operating pressure. This serves as a qualitative check but quantitative information on safe operating pressures must be obtained by subjecting the vessel to hydraulic pressure and measuring the deformation. Some laboratories[***] use the Lamé (maximum principal stress) formula and increase the pressure until a deformation of 0.001 inch has been reached as measured by a dial gauge. Wire strain gauges cemented to the cylinder wall are very satisfactory for this measurement and permit remote readings. If the calculated deformation from one of the design formulae is plotted together with the measured deformation as a function of pressure, the point at which the measured deformation begins to deviate from the calculated value may be taken as the maximum pressure to which the vessel can be safely subjected without exceeding the elastic limit of the metal.

The choice of materials with respect to creep is discussed by Boomer[‡] and with respect to hydrogen embrittlement by Cox.[§§]

Closures for high-pressure vessels have been the object of much investigation and range from simple gasketed screw plugs or flanges to the rather complicated breech-type quick-opening closure.[††] The type of closure is largely determined by the pressure, the size of the opening in the vessel and the frequency of opening. For the present discussion, relatively small vessels for use at high pressures will be considered. Since these vessels are for experimental programs, the frequency of opening the closure may be quite high. For pressures in the range up to 5000-8000 psi, the compression head closure has proven satisfactory. As shown in figure III.81, this consists of 1. an outside cap that screws onto the body of the reaction vessel, 2. thrust bolts, 3. a hardened steel thrust ring that keeps the thrust bolts from marring the pressure head, 4. an inner pressure head and 5. a gasket. The gasket may be a flat metallic gasket or a hardened steel V-ring, the latter being used for extreme pressures. This type of closure has many advantages. It is relatively quickly assembled and closed without the use of heavy wrenches. The multiple thrust bolts permit an equal pressure around the gasket seal and maintenance is low because the machine work is not critical and the gasket may be replaced easily.

At higher operating pressures, except for vessels of small inside diameter, the use of the self-sealing modified Bridgman closure is advantageous. As shown in figure III.82, this consists of 1. a main nut, 2. a lock nut, 3. a thrust washer, 4. a cover and 5. a seal ring. Very little reduction in the wall thickness at the end of the vessel is required for this closure. After the closure has been assembled, the lock nut is tightened to seal the gasket and then any increase in pressure inside the vessel increases the force of the cover on the seal ring to increase the efficiency of the seal.

Careful machine work is required for these closures and considerable care must be exercised in using them, especially with respect to keeping the sealing ring and its contact surfaces in the vessel clean. The closure is opened by backing off the lock nut part way and unscrewing the main nut which pulls the seal ring and cover out with it. Occasionally there is some difficulty from the seal ring jamming, and the selection of a suitable alloy is essential.

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[*] Glascote Products, Inc.

[†] Blaw-Knox Co. and Struthers-Wells Corp.

[‡] Autoclave Engineers, Inc., "High Pressure Autoclaves, Bulletin No. 5," Chicago, Ill.

[**] Perry, J. H., "Chemical Engineers Handbook," p. 2171 (McGraw-Hill Book Company, New York, 1941).

[§] Boe, C. F., "Simplified Method for Calculating Stresses in Pressure Vessels," Chem. Met. Eng. 53, No. 3, 114-6 (1946).

[§§] Jasper, T. M., "Multi-Layer Construction of Thick-Wall Pressure Vessels," Proc. 9th Mid-Year Meet. Am. Pet. Inst. 20M, No. III 7 (1939). Jasper, T. M. and Scudder, C. M., "Multi-Layer Construction of Thick-Wall Pressure Vessels," Trans. Am. Inst. Chem. Engr. 37, 885-909 (1941).

[***] Carbide and Carbon Chemicals Corporation.

[‡] Boomer, E. H., "The Design of High-Pressure Laboratory Equipment," Can. Chem. Met. 17, 136-9 (1933).

[§§] Cox, J. L., "What Steel to Use at High-Pressures and Temperatures," Chem. Met. Eng. 40, 405-9 (1933).

[††] Clark, E. L., Golden, P. L., Whitehouse, A. M., and Storch, H. H., "High-Pressure Reactions," Ind. Eng. Chem. 39, 1555-64 (1947). Meigs, D. P., "Closures for High-Pressure Vessels," Trans. Am. Inst. Chem. Eng. 39, 769-91 (1943). Meigs, D. P., "Closures for High-Pressure Vessels," Can. Chem. Process Ind. 28, No. 4, 228 (1944).

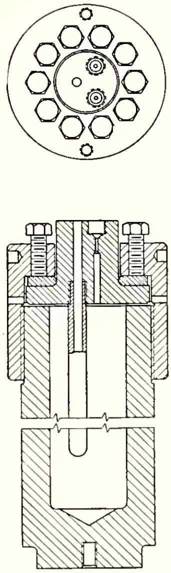

Figure III.81 Typical Compression Closure for Pressure Vessels—American Instrument Company.

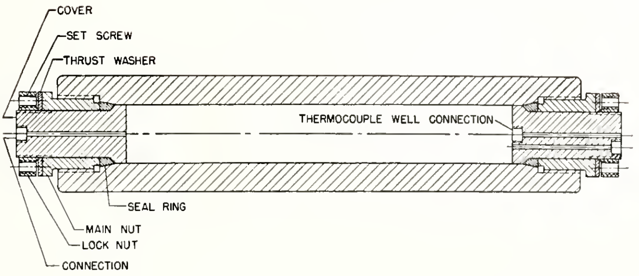

Figure III.82 Modified Bridgeman Closure for Pressure Vessels—Autoclave Engineers, Inc.

Another type of closure is involved in the introduction of observation ports into high-pressure equipment. Caldwell[*] has used a double glass faced Jerguson gauge as a small autoclave at moderate pressures. Poulter[†] describes a glass mounting for withstanding pressures of 30,000 atmospheres. Quartz windows have been used extensively.

COMPRESSORS

Only two laboratory-size gas compressors are available for high-pressure service. The Rix three-stage compressor will operate at pressures up to the range of 5000 psi with a delivery capacity of 12 cubic feet per minute at this pressure. The Norwalk five-stage compressor is available with a discharge pressure of 15,000 psi and a delivery capacity of 8 cubic feet per minute. A modification of the latter is available for compressing gases to 25,000 psi. All of these multiple-stage compressors utilize interstage cooling of the gas during compression.

The pumping of liquids to high pressures is more readily accomplished. Positive displacement piston pumps with single or multiple check valves are generally used.

The measurement of temperature and pressure at high pressures presents difficult problems. Although thermocouples are widely used, the heavy wall thickness necessary for the thermocouple well to withstand high pressures introduces considerable lag in the measurement. Furthermore, in small units and in a thermocouple tube in a line, the heavy mass of metal may cause enough heat loss that the reading is erroneous. Thermocouple blocks are available which introduce the bare thermocouple into the vessel or line but their use is limited by the type of insulating packing for sealing the thermocouple wires and by corrosion problems which preclude contact of the thermocouple with the reactants. Small holes in the wall near the base of the reactor have been used as thermocouple wells, but this is not recommended because of the danger of weakening the vessel. The same disadvantages that apply to internal thermocouple wells will apply in these cases, too.

Bourdon-tube gauges are widely used in high-pressure systems for an indication of the pressure range but are not good for accurate pressure measurement. If precise pressure measurements are required at high pressures it is necessary to use a dead-weight pressure gauge as the standard. These are commercially available for measuring pressures up to 100,000 psi.[‡] A less cumbersome modification that is sufficiently accurate for most purposes is a pressure balance[**] that has an accuracy of ±0.25 per cent up to 25,000 psi. Various electrical devices for the measurement of pressure have been described. Of these, the manganin manometer has been used extensively for very high pressures. It actuates the change in resistance of a wire with a change in pressure. A pressure detector utilizing a strain gauge with a compensating circuit on a hollow metal tube has recently been introduced.[§]

SAFETY AND PERSONNEL

The selection of competent personnel is the best assurance of safety in a high-pressure laboratory, for good judgment and an understanding of the problem will do much to avoid accidents. However, it is not always possible to predict the progress of a chemical

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[*] Caldwell, W. F., "Autoclave for Visual Observation of High-Pressure Reactions," Ind. Eng. Chem. 38, 572-5 (1946).

[†] Poulter, T. C., "A Glass Window Mounting for Withstanding Pressures of 30,000 Atmospheres," Phys. Rev. 35, 297 (1930).

[‡] American Instrument Company, "Superpressure Apparatus, Catalog 406," Silver Spring, Md.

[**] Crosby Steam Gage Company.

[§] Baldwin Locomotive Works.

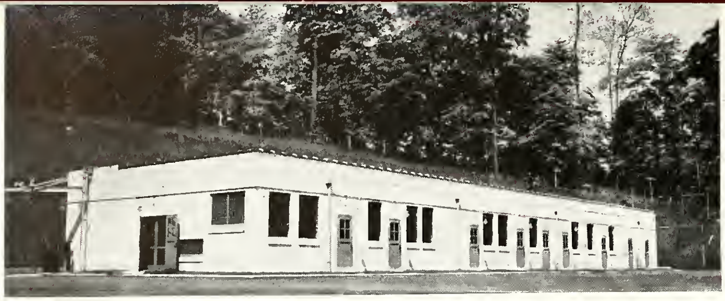


Figure III.83.

Figures III.83, 84, 85 and 86 Hercules Powder Company. Wilmington, Delaware.

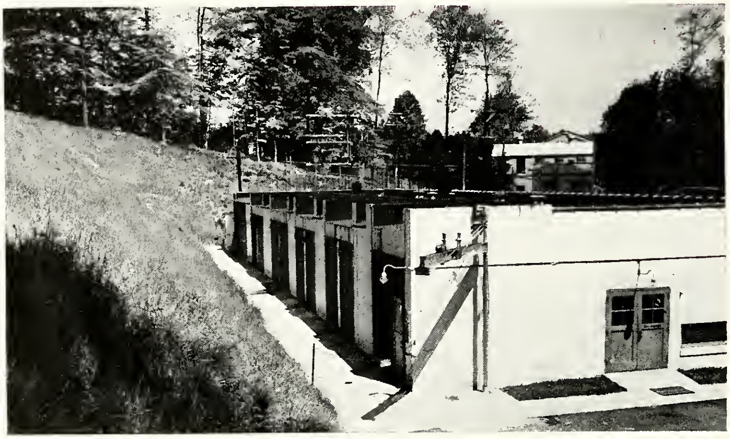
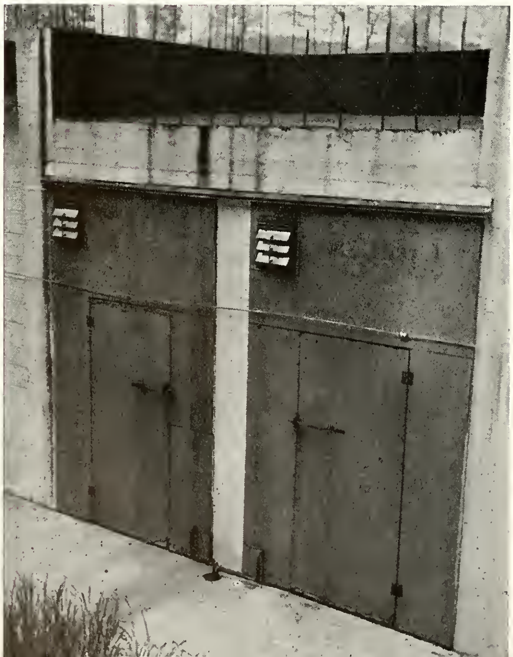


Figure III.84.

Figure III.85.



reaction and, consequently, some provision must be made for protection against an explosive reaction or a pressure vessel failure.

One of the first steps in a safety program is taking and recording the measurements of all pressure vessels before they are used.* Internal and external measurements should be made at specified locations on the diameter and length of autoclaves and auxiliary equipment. These should be checked at regular and frequent intervals. A log book showing the dimensional checks and use history of each autoclave will provide a check on the condition of each and the need for a hydraulic test.

If the manufacturer specifies a maximum rate of pressure and temperature rise, this value should never be exceeded. The maximum temperature differential between the inside and outside of a thick-wall pressure vessel may be calculated, and generally indicates that about one hour is required to heat a 3-liter autoclave

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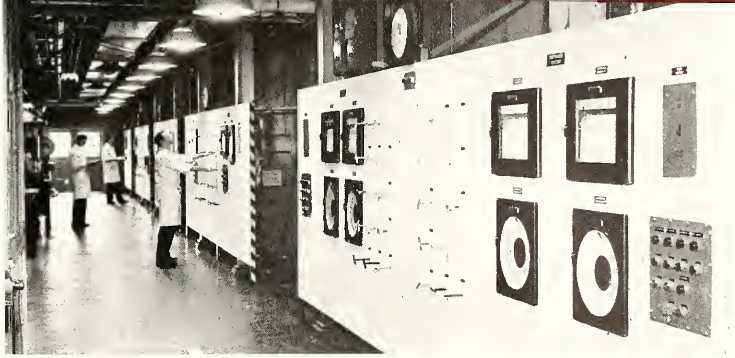
* Gooch, D. B., "Autoclaves," Ind. Eng. Chem. 35, 927-46 (1943).

Figure III.86.



from room temperature to 450°C.* This, incidentally, is one of the limitations in batch autoclave experiments.

The projectile action of ruptured vessels has already been considered in outlining the requirements for barricades. In addition to the installation of suitable barricades, safety requires that certain operating procedures be followed. At no time should makeshift equipment be used for high-pressure work, and specially designed vessels should be used only after they have been hydrostatically tested. Even this hydraulic testing introduces hazards that are often overlooked. Liquids under pressure have an appreciable compressibility which may lead to serious results. If, for example, the threads on the head of a vessel under test should fail suddenly, a projectile action would result. Consequently, even hydraulic testing should be done with the pressure equipment behind barricades.

It should be remembered that gases under pressure have greatly increased solubility in liquids and that this may lead to large increases in the liquid volume. Because of this expansion in volume, it is important to leave at least 50% free space over the liquid to prevent hydrostatic rupturing of the vessel on heating. If no soluble gases are present, 20% free space above the liquid volume is sufficient provided that the liquid volume is calculated at the reaction temperature.†

The apparatus should be set up so that all operations and manipulations can be performed with the operator outside the pressure area and operators should not be permitted behind the barricade when the apparatus is under pressure. If leaks develop around a gasket or at a connection, the pressure should be exhausted before an attempt is made to tighten the joint because of the danger of stripping the threads. The only exception to this rule is in tightening packing gland nuts and even this should be done from outside the pressure area. Another note of warning about personnel entering the pressure area is concerned with terminating the experiment. Experience has shown that detonations can occur after heating and agitation have stopped, even with no pressure showing on the gauge. This incident happened recently in one laboratory and led to the rule that an autoclave should not be handled until thirty minutes after the heating had been discontinued or the peak temperature during a reaction had been reached.

Several chemicals must be handled with caution in high-pressure experiments. Explosive reactions have been reported with ethylene‡ and, in addition, one of the high-pressure equipment catalogues** gives warnings about the use of ethylene oxide, butadiene, and dioxane. Many warnings are issued against the use of oxygen under pressure in standard equipment. Special packings and lubricants are required for its safe use. Tongue§ reports that atmospheric air may be compressed to as high as 2000 atmospheres without danger, even when using lubricating oil. At 2500 atmospheres, little explosions do occur which, although not sufficiently violent to damage the compressor, might blow the safety tube.

Adequate lighting and ventilation are important both in the laboratory and behind the barricades. It is necessary to make provision for local ventilation in the pressure booths to prevent the formation of explosive mixtures from gases that may leak from the pressure system. When toxic gases are being processed, two operators should be present at all times. Explosion-proof lights and fittings are essential because of the danger from gas leaks and as a precaution against a secondary explosion if the gases of a pressure vessel are exhausted into a room through failure of the pressure equipment.

Two exits should be provided for even a small laboratory and more for larger ones. Riot-bar latches should be used on the doors to permit rapid evacuation from the room.

Bourdon-tube gauges are generally the weakest part of the pressure system and they should be mounted behind the panels. Glass fronts should be removed and the back of the case should either be a spring back or it should be drilled with several large holes to permit rapid release of gases. Observation of the gauges and equipment may be done with mirrors or slits and mirrors.

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* Clark, E. L., Golden, P. L., Whitehouse, A. M., and Storch, H. H., "High-Pressure Reactions," Ind. Eng. Chem. 39, 1555-64 (1947).

† Hanson, E. S., "Pressure Equipment Hazard," Chem. Eng. News 26, 2551 (1946).

‡ Bolt, R. O., and Joyce, R. M., "Laboratory Explosions with Ethylene and Carbon Tetrachloride," Chem. Eng. News 25, 1866 (1947). Waterman, H. I., Ressels, W. J., and Van Steenis, J., "Explosive Decomposition of Ethene," J. Inst. Petr. 33, 254 (1947).

** American Instrument Company, "Superpressure Apparatus, Catalog 406," Silver Spring, Md.

§ Tongue, H., "The Design and Construction of High-Pressure Chemical Plants" (Chapman & Hall, Ltd., London, 1934).

10

LABORATORIES FOR ELECTROCHEMISTRY

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GENERAL REQUIREMENTS

There is little difference between electrochemical laboratories for educational institutions and industrial research laboratories as they all require special facilities with respect to electric power, preparation rooms or shops, ventilation and control equipment. Other common facilities which are not necessarily limited to electrochemical laboratories are balance rooms, electrical measuring apparatus, the usual supply of gases, steam, water, vacuum, etc. The different kinds of electrochemical laboratories may be classified as those for:

1. Elementary instruction in electrochemistry
2. General electrochemical research without highly specialized facilities
3. Electrodeposition research and development
4. Corrosion research and testing
5. Electrothermics
6. Special laboratories for the study of batteries, electronics, electrolysis, etc.

LABORATORIES FOR ELEMENTARY INSTRUCTION IN ELECTROCHEMISTRY

The laboratories for instruction in the general principles of electrochemistry require the usual type of chemical tables supplied with direct current so arranged that voltages up to several hundred are available. The tables should be supplied also with a thousand-cycle alternating current for use in conductivity experiments. The other usual facilities of vacuum, gas, water, steam, etc. are required. It is preferable to have a stock room containing the various electrical measuring instruments and controls such as rheostats, small stirring motors and the like, from which the students may obtain these facilities. Associated with the stock room should be a small shop area for the preparation of specimens and other mechanical operations.

GENERAL ELECTROCHEMICAL RESEARCH

In laboratories for general electrochemical research, laboratory tables with stone or wooden tops are required to avoid electrical short circuits and other accidents. The arrangement of the tables should be such as to permit frequent rearrangements of apparatus. The normal services, such as gas, vacuum, alternating current, etc., should be supplied in much the same manner as in any other chemical laboratory. It is desirable to segregate experiments in measurements of electrode potentials by means of sensitive electrical measuring apparatus from other types of work, such as electroplating experiments, where spillage of solution and spray may damage the equipment. Where possible, a supply of low-voltage high-amperage direct current should be made available on the laboratory table, otherwise, separate rectifiers should be provided for each project. Wall-mounted recording potentiometers have been found to be an asset in laboratories of this type when provided with a suitable system for distributing the input to the potentiometers. A typical arrangement for electrochemical research is shown in figure III.87. The working batteries under the table, the busbar along the wall, the potentiometers and conductivity bridges, the calomel half cells and the slide wire potentiometers are all familiar items in a laboratory of this type.

ELECTRODEPOSITION RESEARCH AND DEVELOPMENT

In laboratories for electroplating research, direct current up to about 15 volts is required either in the form of a bus bar system from generators or in the form of a

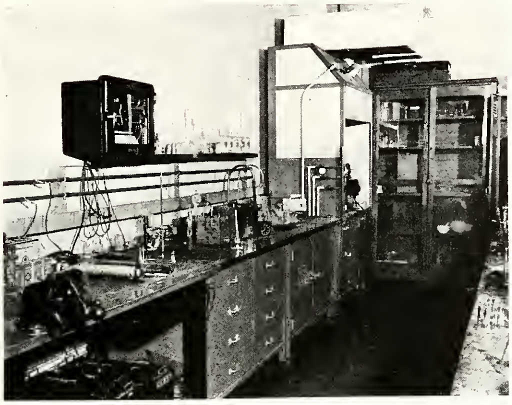


Figure III.87 Electrochemical laboratory showing facilities for making single-electrode potential measurements (courtesy of Bell Telephone Laboratories, Inc.).

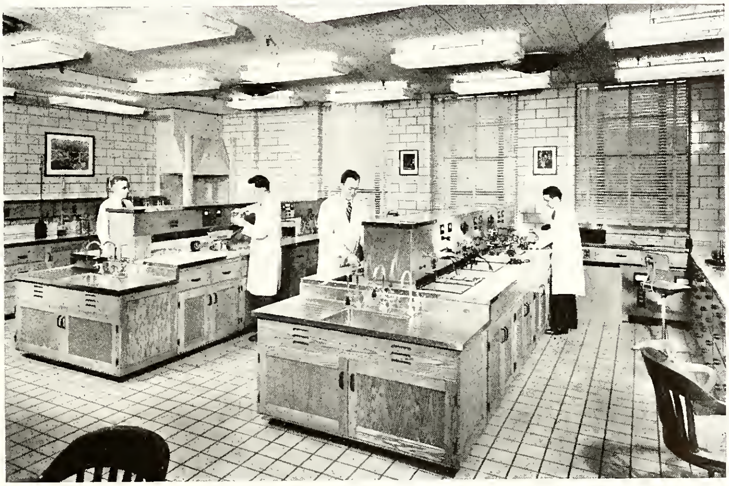
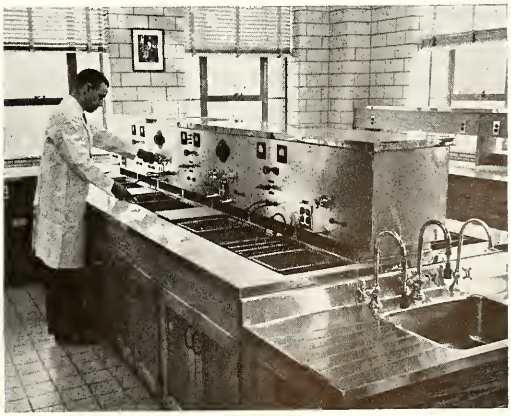


Figure III.88 Electroplating research laboratory showing the arrangement of the work tables and the general layout of the room (courtesy of the Westinghouse Electric Co.).

number of individual rectifiers. Facilities for controlling the temperature of experimental plating baths, either in the form of thermostats or heat exchangers, should be provided. The actual use and handling of plating and related solutions should be carried out in one restricted area provided with suitable ventilation. A separate area should be provided in which the tests on the deposits are made. These tests may involve metallographic techniques employing microscopes, presses for imbedding specimens in plastic, cutting and polishing tables, as well as magnetic and other mechanical tests. The chemical tests on the deposits as well as the chemical control of the plating solutions may be carried out in the general area, provided suitable load facilities are available. An excellent layout for this type of work is shown in figures III.88 and III.89.

In the arrangement of facilities for pilot-plant type of

Figure III.89 Work table in electroplating laboratory (courtesy of Westinghouse Electric Co.).



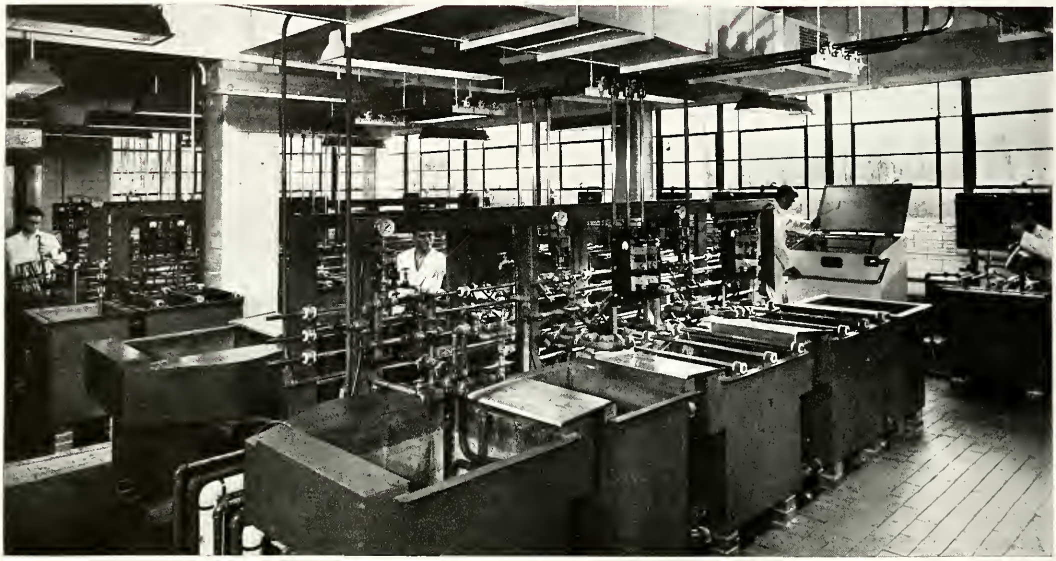


Figure III.90 Electroplating laboratory pilot plant showing arrangement of tanks and services (courtesy of Hanson, Van Winkle Munning Company).

plating studies, the laboratory designer must be mindful of the frequent change in plating solutions and plating conditions. Adequate supplies of power, both DC and AC, cooling and rinsing water, adequate ventilation and an acid-resisting floor are essential. In general, the arrangement of tanks should be such that they may be later interchanged. Space should be provided for filter presses associated with a particular bath. Shop areas for the preparation of racks, buffing and polishing, and other operations should be provided. Adequate controls for temperature and voltage or current are necessary. A storage room should be provided for stocks of plating chemicals, acids and anodes. Figures III.90 and III.91 show a modern pilot-plant type of plating laboratory.

CORROSION RESEARCH AND TESTING

Corrosion-research laboratories are similar to those for general research in electrochemistry, but, in addition, require special potential-measuring equipment for single-electrode potential measurements and facilities for examining and testing corrosion products, such as microscopes and analytical equipment. A typical area in a corrosion research laboratory is shown in figure III.92. Here a recording potentiometer and a precision potentiometer are shown set up for the measurement of electrode potentials and the determination of polarization curves. The microscope table and the balance for the examination and weighing of corroded specimens or corrosion products are shown.

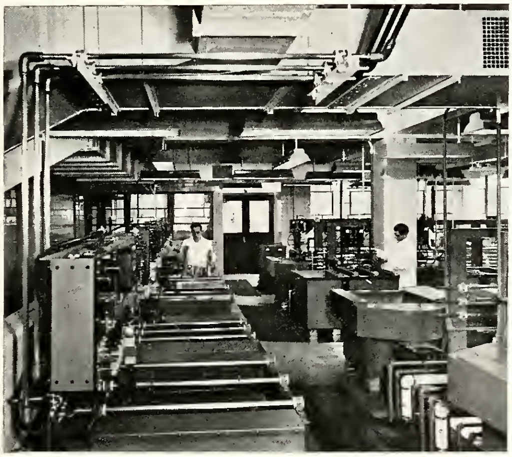
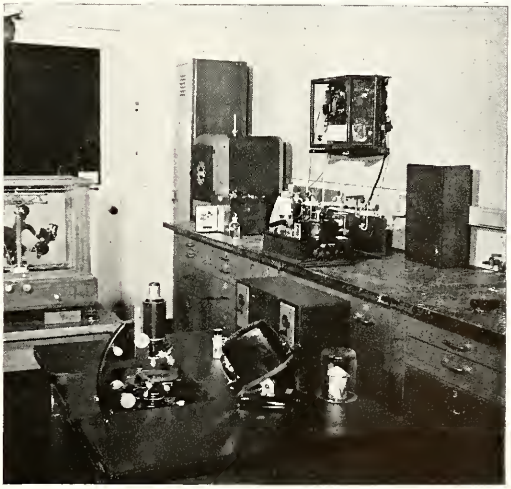


Figure III.91 Electroplating laboratory pilot plant showing arrangement of tanks and services (courtesy of Hanson, Van Winkle Munning Company).

Figure III.92 Corrosion laboratory showing facilities for making potential measurements and microscopic examination of corroded specimen (courtesy of Bell Telephone Laboratories, Inc.).



Laboratories for corrosion testing require special facilities such as salt-fog chambers, alternate-immersion apparatus, humidity chambers and facilities for providing a controlled contaminated atmosphere. Provision must be made for cleaning and weighing corroded test specimens. A salt-fog chamber is available from an industrial supplier, but most of the corrosion testing facilities must be custom built.

ELECTROTHERMICS

The electrothermic laboratories require special sources of power to operate the furnaces, adequate ventilation for the removal of heat, and flooring material which will withstand accidental spillage of hot materials.

SPECIAL LABORATORIES

Typical of special laboratories would be one devoted to the study of storage batteries. Here, aside from the facilities for making experimental batteries and studying electrode phenomena, one finds equipment for making life tests in varying degrees of elaboration.

11

AUXILIARY FACILITIES AND SERVICES

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The technical payroll of a research laboratory constitutes its greatest single expense. Failure to provide adequate and suitable auxiliary services and facilities to allow such personnel to work conveniently and efficiently is false economy. The facilities about to be discussed are found in most well-organized research laboratories. Their scope is commensurate with the size of the laboratory, the types of research undertaken, and the operating budget. Wherever possible, these factors will be taken into account in the discussion.

LIBRARY

A technical library suitable for a research laboratory employing 100 technically trained people will probably contain 250 to 500 volumes and 500 to 1000 pamphlets at the end of the first two years. A laboratory of 500 research workers might reach 2000 volumes with 1000 to 2000 pamphlets in that period.

It has been found* that 100 "average" volumes occupy a single-faced shelf section 3'0" by 7'6" high. Stack space can be estimated fairly accurately by multiplying the total number of volumes to be accommodated by 0.09 to give the area requirement, and by 0.676 to give the net cubic requirement. It is estimated that a technical library normally doubles every 12 to 15 years. As an economical solution to the problem of expansion, many modern research libraries have adopted a high-ceiling design which will accommodate two-story stacks.

The reading room and the librarian's offices should be separated by a sound-proof partition. This partition should be partially glazed, so that the librarian can keep the reading room area under surveilance at all times. The office and reading room require acoustical ceiling and floor treatment to keep the general noise level at a minimum. Well-designed lighting will provide 40 to 60 footcandles of practically shadowless illumination in the reading room. The stacks are lighted by special fixtures marketed for the purpose.

In addition to one or more large reference tables in the reading room, a number of semi-private study nooks, or carrells, will be found most useful. The library staff should be provided with suitable work space for binding, repairs, and cataloging. Consideration should be given to space for card files, microfilm storage, microfilm readers, and photostatic copying devices.

STOCK ROOM

Even in relatively small research laboratories, the inventories of stored supplies run into surprisingly high figures. Therefore, it is well to plan adequate stock room space, conveniently located. In small laboratories, it is possible to stock laboratory supplies, chemicals and stationery supplies in a single stock room. In larger laboratories it is advisable to dispense different types of supplies from separate stock rooms, located near the center of demand. Bulk supplies of materials should, if possible, be located in warehouses or basement storerooms so as not to take up space better suited to experimental work.

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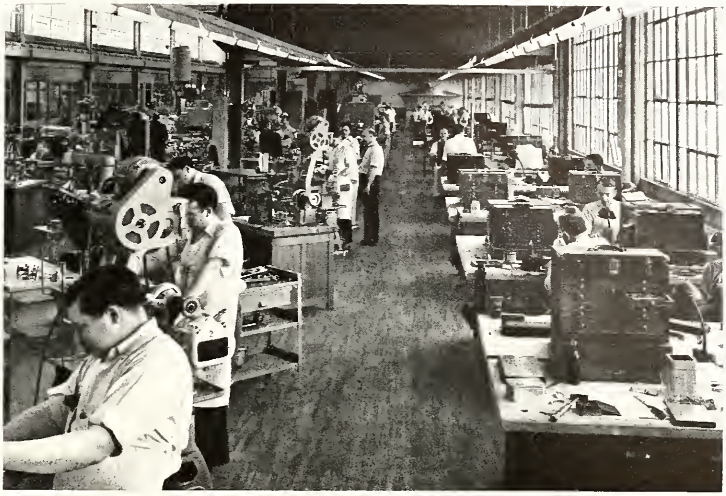
* R. W. Henderson, Library Journal, 59, 382, 865 (1934); 61, 52 (1936).

Figure III.93 View of Gulf Engineering Instrument Shop.



STEAM, COMPRESSED AIR, VACUUM, ETC.

The types of utilities or services distributed to various locations in a laboratory building depend upon the type of work carried on. If the distribution system is so designed that additional piping and wiring can be installed economically and conveniently at any time, a minimum number of services may be given general distribution initially, and additional services installed later as needed.*

Regardless of the type of research work involved, electricity, hot and cold water, and fuel gas can be considered essential in most laboratory locations. In chemistry laboratories compressed air, vacuum, and possibly low- and high-pressure steam can be added to the list of essential services. Unless a high and constant demand for the latter is indicated, as in pilot plant areas, it is usually more convenient and economical to resort to electrical or gas heating, or to generate steam by some means which can be controlled locally and according to individual requirements. In physical laboratories direct current and polyphase alternating current of various voltages probably will be in demand.

It is generally unwise to pipe such gases as nitrogen, carbon dioxide, oxygen, and hydrogen from a central source unless the demand is constant and permanent. If it is felt that provisions must be made for a central supply of special gases, a building design which includes the placing of service shafts vertically at optimum intervals is favored, since it allows for distribution to specific locations from central supplies in the basement.

General distribution of purified water may or may not be necessary, according to demand. The purity and amount of purified water needed should be carefully studied before the distribution system is designed or any equipment specified. For many laboratories demineralized (deionized) water is sufficiently pure for most work. Where relatively small amounts of extremely pure water are required, it may be supplied from small stills located in laboratories, may be distributed from a central still in bottles, or piped into specific locations through a vertical service shaft from an automatic still located in a penthouse or loft. If the demand for de-mineralized or distilled water in a large laboratory building is great, it is preferable to install two or more purification units totaling the estimated required output. This not only simplifies the piping in many instances, but provides for emergency service when a unit is undergoing repair or cleaning. Units should be so located in the building that gravity flow rather than pumping will be used. It is desirable to provide storage tanks of sufficient capacity that peak demands can be met without having to install units of excessive continuous output.

MACHINE AND INSTRUMENT SHOP

Machine shop facilities are almost indispensable in research. In the case of small laboratories, the shop probably will be used by the research workers themselves. It will be found, however, that where the number of technically trained people exceeds 20 it will pay to man the shop with an adequate number of experienced machinists. Laboratories with 100 to 500 technical employees find it necessary to have machine and

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*** "Symposium on Design and Construction of College and University Chemistry Laboratories," J. Chem. Ed., 24, 320-353 (1947). "Symposium—Construction and Design of Research Laboratories," Ind. Eng. Chem., 39, 440-461 (1947).**

instrument shops with staffs of from 15 to 50 machinists and instrument makers, depending upon the type of research.

The equipment in research laboratory machine shops should be of the highest grade and cover as wide a range of operations as feasible. The arrangement of equipment and operations should be carefully worked out with the aid of an experienced machinist in order to insure the most efficient layout from the standpoints of flow of work, circulation and distribution of personnel, and safety.

The shop quarters should be well-designed, with good lighting and ventilation. Special consideration should be given to floor covering, which should be comfortable to the feet, resistant to oil and grease, and should be resilient enough to prevent serious damage to work and tools which are dropped accidentally. Though expensive, inlaid treated wooden block floors satisfy these requirements and, if well-laid, have a long life. Modern industrial color schemes contribute greatly to employee efficiency and safety in shop areas and should not be overlooked in designing a new machine shop or modernizing an old one. The additional cost of scientific color treatment is negligible. Leading paint manufacturers furnish expert consultants at no cost.

In addition to general machine shop facilities, large laboratories frequently have need for an instrument shop or laboratory (see figure III.93) where instruments of all kinds can be calibrated, adjusted, and repaired. In conjunction with such a unit an instrument loan service is sometimes provided.

CARPENTER SHOP

Even in a large laboratory (500 to 1000 total personnel) a carpenter shop, while necessary, need not be extensive. Sufficient power tools should be provided for the convenient fabrication of relatively simple wooden articles. The same standards of ventilation and lighting provided in other shop areas apply to the carpenter shop. Because of noise and dust the shop should be located in a basement, or better, a separate service building. Sufficient storage for materials should be located in or near the shop.

GLASSBLOWING

The need for, and scope of, glassblowing facilities depend for the most part on the type of research performed.* An experienced glassblower will have his own ideas on equipment and he should not be denied such equipment as he reasonably can justify. His skill can be used most efficiently if he has such aids as glassblowing lathes, power cutting wheels, good annealing furnaces, and the various special burners which increase his versatility.

The glassblowing shop should have the best possible lighting and ventilation. The intense heat from large-scale glassblowing operations must be removed from the shop rapidly without disturbing the burner flames. This can be accomplished best in a room of large volume, which, if floor space is to be conserved, indicates a high ceiling. Acoustical treatment of glassblowing shops is very desirable because of the noise from the blast lamps and annealing flames which must be used in certain operations.

DUPLICATING AND PHOTOSTATING

A research laboratory disseminates the results of its investigations through reports, memoranda, or letters, usually distributed to a number of interested persons. If the extent of such distribution exceeds the number of legible carbon copies which can be produced by manual or electrical typewriters, additional duplicating facilities will be needed.

Depending upon the maximum number of copies desired and the type of material to be duplicated, devices for text reproduction will range from the relatively inexpensive Ditto-type duplicator to the manually or electrically operated Mimeograph or lithographic machine. The total floor area required for these units, including sufficient table space for assembly and binding, will approximate 200 square feet.

In research laboratories where mechanical designing is involved, there usually will be a demand for reproduction of drawings by blueprinting, dry printing, or continuous Ozalid-type dry printing. If the demand for such reproductions is small and the number of prints limited, the equipment probably will comprise a printing frame and a developing tube for simple dry process reproduction. The frame will consist of a plate glass with a removable cover, the size to be determined by the size of the tracings to be handled. A bank of printing lights, such as carbon arc lamps or low-pressure mercury-vapor lamps, may be mounted over the frame to provide a light source. If a large number of prints is desired and the total daily volume of work is great, machines such as the 54-inch continuous blueprint machine or the 54-inch Ozalid "Printmaster" will be needed. A large, continuous blueprint machine covers approximately 72 square feet while a comparable Ozalid machine requires approximately 24 square feet. For either process sufficient table space must be provided for trimming and collecting prints.

In some cases, where it is desirable to publish especially attractive reports, with printed covers and title pages, a small job-printing press will be found useful. About 80 square feet of floor area will be required for this unit.

Many research laboratories find need for photostat facilities for copying printed matter, maps, drawings, and technical articles from journals and books. The smallest photostatic device occupies approximately 40 square feet of floor space. It is pointed out that the largest continuous photostat machine with self-contained processing facilities occupies slightly less total floor space than the smallest non-continuous unit, which must have separate developing, fixing, washing, and drying facilities.

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* W. E. Barr and V. J. Anhorn, "Scientific and Industrial Glass Blowing and Laboratory Techniques," Instruments Publishing Co., Pittsburgh, Pa., 1949.

In considering the auxiliary equipment necessary for duplicating and photostating, the importance of sufficient storage space for paper stock, sensitized paper, and similar supplies is stressed. A laboratory sink emptying into a chemical sewer is desirable, also. In conjunction with the sink a small laboratory table should be considered for mixing solutions.

The room in which duplicating and photostating processes are carried out should be well-ventilated so that fumes from one process will not interfere with other processes. The lighting should be good, with 60 to 100 footcandles at the working surfaces. In the photostating area the lighting should be under separate control. A floor covering conducive to foot comfort is recommended.

PHOTOGRAPHY

Most research laboratories require some sort of photographic service for recording tests, and to provide illustrations for reports and publications. The scope of these facilities will vary according to the size of the laboratory and the type of research. Smaller laboratories will find it convenient and economical to combine photographic and duplicating services. The equipment needed for occasional photographic work is inexpensive and may be operated by untrained personnel. Larger laboratories usually find frequent use for this service and have found that it is necessary to provide well-equipped and well-designed photographic laboratories, operated by experienced personnel. Provision must be made for the convenient mounting and positioning of cameras, lights, and subjects.

Darkrooms should meet commercial standards from the standpoints both of design and equipment. Considerable attention should be given to good, dustless ventilation. If the budget permits, the darkroom and studio should be air conditioned. Many schemes have been used for light-locked entrances through which to enter and leave darkrooms while work is in progress. These may be seen in almost any of the large, modern research laboratories.

CONFERENCE ROOMS

Since successful research is the product of many minds under good direction, the technical conference is indispensable in a research laboratory. Therefore, an adequate number of well-designed conference rooms should be conveniently located throughout a laboratory. In a large research organization it is generally advisable to provide a number of small conference rooms, seating from 10 to 15 persons, rather than one or two larger rooms. On occasions which demand a room of considerable seating capacity it is possible to combine two small rooms through the use of a collapsible dividing partition.

The equipment of these rooms will include a sufficient number of comfortable armchairs and a large conference table which, if possible, should be of the round or oval variety. The equipment also should include a large, illuminated blackboard and facilities for the projection of slides and motion pictures. It is well to have at least one conference room equipped for disc or wire recording. In rooms with seating capacities of less than 20 persons, special acoustical treatment is unnecessary except for a floor covering of material which will reduce to a minimum the scraping of feet and chairs.

In the case of laboratories with technical staffs exceeding 200, an auditorium will be found useful in addition to the smaller conference rooms. The auditorium should seat at least 100 people, and preferably should be arranged with a sloping floor to afford good visibility. It should have ample blackboard space, and be provided with good projection facilities located in a projection booth to eliminate noise from motion picture equipment. A public address system is not necessary in an auditorium of less than 250 seats but, because of the increased use of motion pictures with sound, a well-engineered sound system should be provided. The technical auditorium should be equipped either with a permanent lecture demonstration table or with a portable table which can be put in place when needed and connected to services concealed in the floor. Where lecture demonstrations are contemplated, a small, well-equipped preparation room should be located close to the lecture table.

Particular attention should be given to the ventilation of conference rooms and auditoriums. If the laboratory building is not air conditioned, air conditioning of the meeting rooms themselves should be considered.

CALCULATING ROOM

Calculating rooms should be well lighted, with from 60 to 100 footcandles available at working surfaces. Through acoustical treatment machine noise can be reduced to a low level. Sufficient electrical outlets should be provided, located as conveniently as possible to the equipment. Well-designed computing machine desks are available from office furniture manufacturers. These have ample working space for spreading out books, papers, sketches, and large data sheets, and at the same time provide for placing machines properly for convenient and non-fatiguing operation.

VAULTS, FILE AND STORAGE ROOMS, COLD STORAGE

In general, the modern laboratory is not equipped with vaults except where narcotics, large amounts of tax-free ethyl alcohol, or special valuable materials are concerned. Where a vault is necessary it should occupy space in the basement of a laboratory building or in a separate out-building designed for the purpose.

Planned storage space for inactive files and equipment is notably lacking in some of the finest and most modern research laboratories. If ample space is not provided for the storage of old correspondence and research records, this material gradually becomes scattered until finally it can be found only with great difficulty. Centralized file storage preferably should be located in the basement because of the excessive floor loading. Such a room should be provided with some ventilation and should be carefully protected from dampness. The installation of an automatic fire-control system is justified. Clean, well-designed storage space should be provided for research equipment which is not in active use. Cabinets and shelving should be furnished to encourage orderly storage. An inventory file of stored equipment should be set up and regularly maintained. Large research centers have in many cases established warehouse and storage buildings for efficient control of active and inactive inventories.

Cold storage rooms are necessary only where large quantities of materials requiring such storage are concerned. For small-lot sample storage, domestic or commercial electric refrigerators afford greater economy and flexibility than cold storage rooms. Where larger facilities for moderately low temperatures are needed, prefabricated commercial "walk-in" refrigerators are available in almost any size. They not only can be installed more cheaply and easily than built-in types, but can be dismantled, moved, and reassembled at will.

CAFETERIA

Unless a research laboratory is located close to good, reasonably priced eating facilities, it is usually desirable for the laboratory to furnish such facilities for its employees. This service may range in scope from the "dairy bar" type to the full-scale cafeteria with complete menus, and may be laboratory-operated or operated by outsiders on a concession basis. In either case the laboratory must furnish space suitably designed and equipped. Preferably cafeterias should have high ceilings and should be carefully treated acoustically to reduce the high noise level inherent in the operation. Wall and floor materials which can be cleaned easily should be chosen. The heating and ventilating system should be designed for highest efficiency. Moderate air conditioning is desirable but not necessary. Every attempt should be made through design and color treatment to provide a dining area with as pleasant an atmosphere as possible.

Cafeterias should be planned with the assistance of qualified experts. Particular attention should be paid to the most efficient arrangement and use of the equipment,* with due consideration to future requirements. Estimation of dining room and kitchen space may be arrived at fairly accurately from unit figures derived from extensive surveys of established industrial cafeterias.†

The size of dining areas may be predicted by assuming 17 square feet per patron seated. The resultant figure will include all aisles, as well as dishwashing and serving space, since the latter are dependent upon the number seated at one time, rather than on the total meal load. Thus, in a laboratory where it is expected that 100 persons will be served at one time, dining room, serving, and dishwashing space totaling 1700 square feet will be required. Since efficiently arranged serving and checking facilities will allow eight to ten diners per minute at the most to enter the dining area, all should be served in 10 to 13 minutes.

When the number of meals served at one time exceeds 200, staggering of lunch periods should be considered. If 200 diners are divided into two shifts, 30 minutes apart, a dining room which seats 100 and has a gross area of approximately 1700 square feet can be used. For 300 diners the same 1700 square feet can be used by having three shifts arrive twenty minutes apart (twenty minutes is the minimum average time of occupancy which can be assumed per patron). It is readily seen, then, that as many as 400 persons can be served in less than an hour and a half in a net dining area of less than 1700 square feet, with a seating capacity of only 100. If more than 100 persons are to go through the serving line at one time, the establishment of duplicate serving facilities should be considered.

Kitchen areas can be calculated with reasonably good accuracy from the following table:‡

Industrial Cafeteria
Kitchen Area Coefficients

Meal Load	Base Figure	Coefficient, Sq. Ft.
100- 200	200	5.00
200- 300	300	4.00
300- 400	400	3.50
400- 800	800	3.00
800-1300	1000	2.50

The table shows that the area coefficient (square feet per meal) decreases as the meal load increases. Thus, while 200 meals would require a kitchen area of 1000 square feet, 400 meals would require only 1400 square feet. These areas include dry storage, refrigerated storage, baking, meal preparation and cooking area, desk or office space for the manager, cafeteria employees' dressing rooms, and garbage disposal. Obviously, kitchen requirements depend upon total meal load only, and are not affected by staggered arrival times. However, the staggering procedure does effect economies in dishwashing and serving facilities as well as in the number of tables, chairs, trays, dishes, glasses, and tableware needed.

In equipping the kitchen it is best to enlist the aid of restaurant experts. Only the most modern equipment should be considered. While the initial cost may appear high, maintenance will be low and efficiency high.

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* A. W. Dana, Restaurant Management, March, 1948, p. 44.

† A. W. Dana, Restaurant Management, March, 1948, p. 44. E. G. Adelberger, Industrial Relations, December, 1948, p. 29.

‡ E. G. Adelberger, Industrial Relations, December, 1948, p. 29.

REST ROOMS

An adequate number of clean, modern rest rooms constitutes an important contribution to employee morale and satisfaction. Cost should be secondary to design for these facilities. Careful study should be given to lighting, ventilation, and color schemes. Usually the location and basic design can be left to the architect, who should pay particular attention to easy maintenance and efficient arrangement.

The number of rest rooms and their size should be based on maximum future requirements, as the installation of such facilities in an established building is costly and generally unsatisfactory. Usually it is found that, as laboratories expand, the number of female employees increases because of clerical demands, and rest room facilities for women should be designed and located to take this into account. If dispensary cot facilities are not provided or are not conveniently located, sufficient retiring space should be provided in conjunction with women's rest rooms. The men's rest room serving executive offices can be provided with a small adjoining lounge for the convenience of visitors.

LOCKER AND SHOWER ROOMS

Locker and shower rooms should be located as close as possible to work areas which require such facilities. Pleasant, airy, well-lighted locker rooms pay dividends in employee satisfaction and good will, and considerable thought and planning should go into their design.

Lockers should be large enough to accommodate comfortably the clothing and equipment of the employee and should be selected on the basis of single occupancy. Sloping tops eliminate the unsightly and unsanitary accumulation of articles on top of the lockers. The lockers and dressing benches should be mounted on top of low, built-in, coved concrete bases to facilitate floor cleaning. Aisles and dressing space should be as spacious as practicable.

Shower, washing, and toilet facilities should be designed and arranged for efficient traffic circulation. They should be generous in capacity, with sufficient excess to take care of maximum contemplated expansion. This excess can be installed initially at a fraction of the cost of later installation in converted or added space.

Free use of glazed tile is justified in locker and shower rooms because of easy maintenance. Ventilation should be carefully designed so as to be not only efficient but as draftless as possible. Lighting should be well-distributed and of suitable intensity (25 to 30 footcandles at waist level). Attention should be given to such details as electrical outlets, mirrors, towel racks, et cetera.

FIRST AID

In small laboratories first-aid facilities usually consist of first-aid cabinets in laboratory rooms or corridors. In laboratories of 50 to 200 people it is desirable to provide a first-aid room equipped with a well-stocked supply cabinet, a cot, and a wash basin. Large laboratories (over 200 people) usually employ a full-time trained nurse and in many cases a visiting physician. Such laboratories should plan on an office, an examination room, a suitable number of small retiring rooms with cots, a small laboratory, and a lavatory. The selection of equipment for the first-aid department usually is made by the nurse or doctor.

12

PILOT PLANT LABORATORIES

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The modern pilot plant laboratory houses equipment which consists of small-scale replicas of commercial process equipment. The various pieces of equipment may be interconnected to simulate an integrated small-scale plant, or used individually to study one or more parts of a process.

The chief function of pilot plant studies is to gain operating and design data which may be extrapolated with confidence to large-scale operation. A secondary function is the preparation of a sufficient quantity of a new or improved product for market evaluation. In some cases, pilot plant installations of moderate size are also used for interim production of products while the market is being expanded or a commercial plant is being built. Semi-works plants or highly specialized pilot plants that require a comparatively large number of process steps are usually housed in separate buildings and are not considered in this discussion.

From the foregoing it is obvious that the pilot plant laboratory must house equipment and service facilities of maximum flexibility if it is to be used efficiently. As far as possible, equipment must be built of materials that are corrosion-resistant to a wide range of solids, liquids, and vapors to avoid expensive duplication of units. These materials of construction and the required built-in flexibility result in expensive equipment, so the building must be constructed and arranged to allow maximum utilization of equipment and services on a variety of studies.

LOCATION

The pilot plant laboratory is usually located near, and in some cases is operated by, the research department. Close contact with research personnel is imperative, especially in the early stages of pilot plant studies. In many instances it is necessary to return the project to the research department for further study, in which case proximity of pilot plant and research laboratory facilities is advisable. In those cases where the research department is located at a distance from the manufacturing department, it may be necessary to locate the pilot plant laboratory near the manufacturing department rather than the research department, particularly if plant by-products not easily shipped in large quantities are used as process raw materials. If raw materials are easily obtainable articles of commerce, it still appears preferable to build the pilot plant near the research facilities. Highly specialized pilot plants and interim production plants could still be built near the factory location.

GENERAL ARRANGEMENT

The basic architectural design of the pilot plant laboratory should provide adequate space in both the horizontal and vertical planes with sufficient flexibility to contract or expand pilot units without cramping. Mechanically, it should provide all the necessary services such as crane, freight elevator, pressure and vacuum pumps, high- and low-pressure steam, electric power and light wiring, water, sewers, etc. From a safety angle, it should provide protection from every possible hazard such as burns, asphyxiation, bodily harm, explosion, poison, dust, heat, skin and membrane irritation, eye injuries, and many other hazards. From a housekeeping standpoint, it must be designed, internally and externally, for easy and efficient cleaning. An adequate disposal system for all types of waste must be provided. From the personnel viewpoint, sufficient office and storage space and also locker, toilet and shower rooms, a controlled heating and ventilating

Figure III.94 Pilot Plant Building. Corn Products Refining Company, Argo, Illinois.

system, and an excellent lighting system are advisable. Facilities must also be provided for ease of ingress and egress of personnel, materials, and equipment.

THE BUILDING

The most desirable type of construction for a permanent pilot plant laboratory (the only kind under consideration) is a structural steel frame exposed in the working area, and fireproofed in the office and locker room area, erected on concrete footings and walls. This type of construction usually costs less and may be fabricated and erected more readily than other types. The wall surfaces are easily adapted to attachments, brackets, hangers, and various changes and alterations. Because the wall surfaces are non-deteriorating, cleanliness and ease of maintenance are simplified.

Floors

Floors should be constructed of reinforced concrete designed for a minimum live and dead load of 350 pounds/square foot in the laboratory working areas, and for 125 pounds/square foot in the service areas. Upper office floors may be designed for 50 pounds. Reinforced concrete floor poured on the ground level will normally carry 1,000 pounds/square foot or more.

In the laboratory area, the high-silica cement concrete floor should be treated with special resistant paints to prevent dusting, indentation, and solution in acid and alkali. Unfortunately, no one coating is known which withstands abrasion, acid, alkali, hot water, and organic solvents. The nature of the work to be done in the area will dictate the particular coating to be used. In special cases it may be desirable to pave certain areas with acid-proof brick or tile.

The laboratory floors should be pitched for quick drainage to troughs or circular outlets with removable gratings flush with the floor and located so as to drain an entire bay (16′ 10″ by 16′ 10″ or 20′ 10″ by 20′ 10″). A suitable pitch has been found to be ¾ inch in 10 feet. One or more dead-level bay areas without drains may be desirable for some construction projects.

In the office area, it is desirable from the standpoint of maintenance, cleanliness, and appearance, to apply either asphalt, rubber, or linoleum tile or sheet on the finished concrete floors. Cork tile may be used in private offices or conference rooms, or in other areas where the employees are on their feet most of the working day, for the purposes of foot ease and sound control. Concrete floors in the locker rooms, toilets, shower rooms, corridors, janitor closets, file rooms, etc., should be treated with special paints or sealing compounds to prevent dusting and wear, and to aid cleaning.

Walls

Exterior walls should be constructed of fireproof materials of a permanent nature. In earthquake or hurricane areas, proper allowances in design must be made. In addition to reinforced concrete, commonly used wall materials are face brick, limestone blocks, and glazed terra cotta backed by common brick.

Interior walls may be built of brick, tile or terra cotta. Glazed architectural terra cotta blocks are particularly suitable for interior walls where cleanliness, inertness to fumes and vapors, and low maintenance costs are desired. The same type of block may be used in corridors, locker and shower rooms, and service rooms. Ease of cleanliness may be enhanced by the use of round corners and cove bases.

In office areas interior wall construction is usually plaster on metal lath. Clay tile, gypsum block partitions, or furred walls may be used. It is common practice to separate the pilot plant working area from the office, locker rooms, and service area by a fire wall. Ceilings in all but open pilot plant areas are commonly of plaster on metal lath. In office areas it has proved advisable to use suspended acoustic ceilings (sound-absorbing blocks).

Windows

Windows in the pilot plant area should allow a maximum of outside light consistent with good structural design. For safety they should be designed to blow out in case of explosion. For good maintenance they should be easily washable and replaceable. Glazed areas of this type usually extend from vertical building column to column in the horizontal plane and from first floor curtain wall sills to the roof eaves in a vertical plane (see figure III.94).

Window frames are usually of a continuous, self-supporting structural design consisting of vertical and horizontal members with horizontal muntins dividing the individual pane openings into a maximum size of 2 feet high by 5 feet long. Larger panes may be used but they are susceptible to wind breakage with consequent hazard to personnel from falling glass.

In the interest of economical window washing and pane replacement, it is desirable to install a continuous row of projected sashes at an intermediate point between each floor level. Window frames and sashes may be constructed of structural steel shapes well painted or of non-rusting materials if conditions warrant. Glass panes should be double-strength clear machine-made glass and, as mentioned above, scored for explosion purposes.

Roof

The roof area should be designed for not less than 25 pounds/square foot live and dead load. Local conditions will frequently make a design load of 40 to 50 pounds/square foot necessary. The roof should be of a fire-resisting or fireproof type supported by structural girders and roof purlins of either the bar-joist or rolled section type. Roof construction may consist of either poured light weight concrete, precast concrete slabs, or metal decking, insulated with 1-inch thick "Celotex" or similar sheets and water-proofed with an emulsified asphalt and paper roofing. Gutters, downspouts, flashing, etc., should be made of 16-ounce soft copper sheets, or similar material.

Doors

Hinged exterior doors should be fireproof metal flush type 2 inches thick with corrosion-resistant door operators and panic hardware. The finish may be natural metal such as aluminum or stainless steel, or baked enamel on steel. All such doors should open outwardly and be marked with suitable red exit lights. The minimum number of doors is usually specified by local fire or insurance regulations. If possible, one door opening should be of sufficient width and height to allow a truck to enter the building. Overhead doors are particularly suitable to this use. In cold climates the door may be so connected with an air blower that a curtain of warm air is blown down or across the opening when the door is raised. This door should not replace an outside loading dock at truck floor elevation, which is highly desirable.

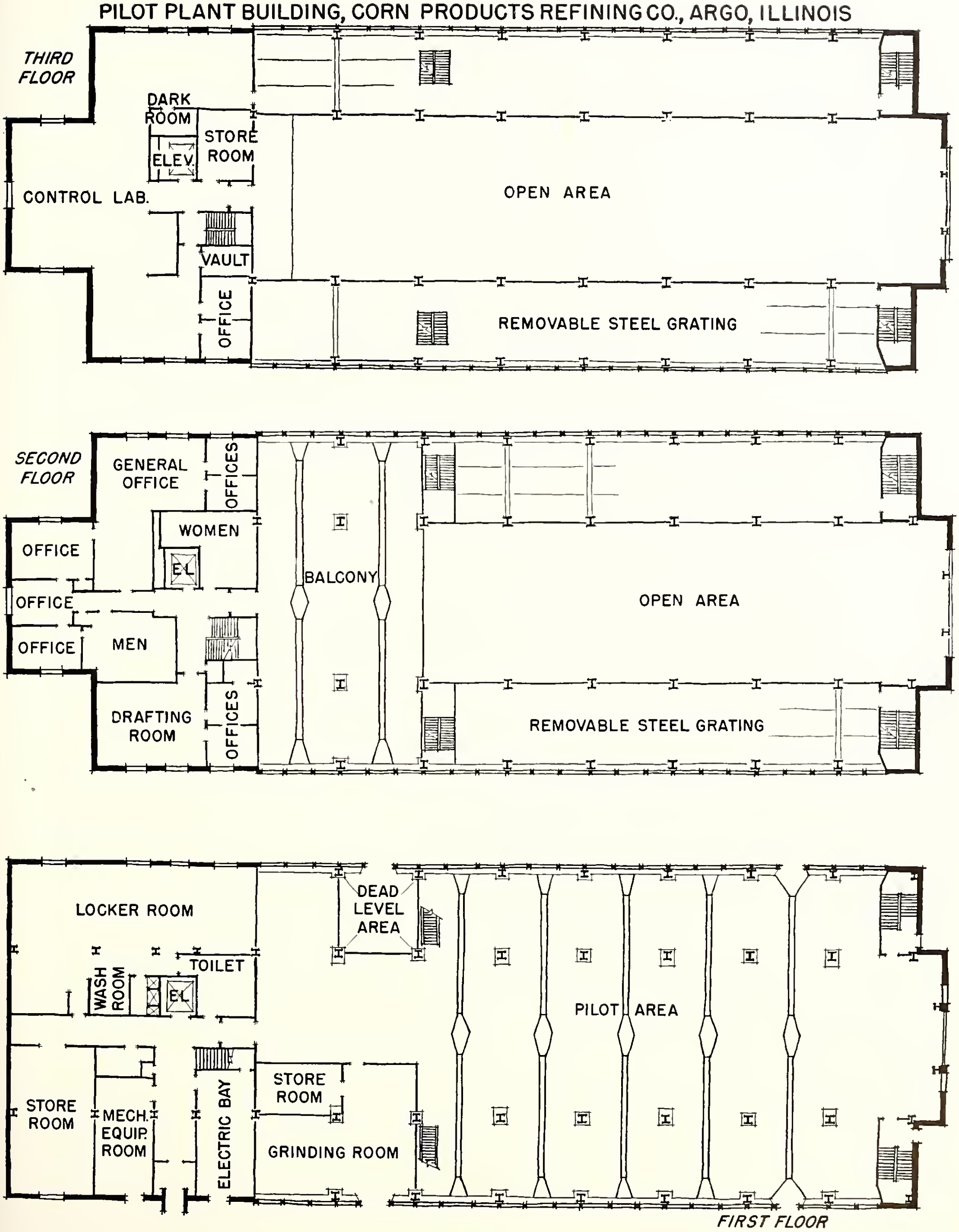
The pilot plant area in modern laboratories is usually separated from offices, stores, shops, and service areas by fire doors and air locks. Fire doors of painted steel should be of the rolling type with fusible-link control. Air locks ordinarily consist of a double set of hinged doors similar to common storm entrances. The rolling fire door is installed on the working area side of the air lock. All hinged interior doors throughout the building should be fireproof metal flush type doors 1¾ inches thick.

Stairs

The number and location of fireproof stairways depend upon the size and shape of the building. An enclosed stair well should be provided in at least one end of the building. These stairs are usually made of concrete, but care must be taken to see that the surface does not become slippery and consequently hazardous. In the pilot plant laboratory proper metal stairs from floor to floor will probably be added from time to time as the needs of particular equipment installations dictate. In any event, all stairs should be provided with handrails.

Space Allocation

The entire space in a pilot plant laboratory building is not available for pilot plant installation and operation. Part of the space will be required for various services, among which the following are most important: locker and shower room, toilets, electrical and mechanical rooms for building services, storerooms, storage facilities, laboratory table space, machine shop, instrument shop, janitor's room, offices, drafting room, conference rooms, control laboratory, and perhaps others. Some of these facilities may be available in nearby buildings, but full consideration should be given each requirement before eliminating it from the pilot plant structure. In this age, locker and shower rooms, and toilets, must be convenient, adequate, and immaculately clean. If both male and female personnel are employed within the building, duplicate facilities must be provided. Rooms for electrical transformers and switch gear should be located in isolated rooms outside the pilot area. The same is true of mechanical building services such as compressors, ventilating fans and blowers, vacuum pumps, hot water heaters, and the like. If the mechanical service equipment which does not serve pilot plant equipment directly is isolated, it will not be misused or abused. In recent years, most pilot plant installations have required Class I Group D



Figures III.95, 96 and 97.

(explosion-proof) electrical equipment. Inasmuch as general service equipment need not be explosion-proof if it is isolated, savings in equipment cost will usually more than pay for the extra room required.

Laboratory table space should be available somewhere outside the pilot area. Small bench-scale setups often yield valuable data that would be time-consuming and expensive to obtain in a pilot plant. Laboratory table space is usually available in the research laboratory, but if it is not *always* available it may be well to install a small laboratory in the pilot plant building. A similar room may well be set aside for small-scale batch preparations, making use of ceramic vessels and laboratory glassware.

If the pilot plant laboratories are going to be used efficiently, adequate analytical laboratory facilities should be available. The volume of analytical work from pilot plant studies is usually sufficient to warrant the establishment of a separate analytical group whose laboratories can well be housed in the pilot plant laboratory building. It is often possible, however, to use the routine laboratories of the manufacturing department for analyses of pilot plant samples.

Storerooms per se need not be in the pilot plant laboratory building, but *storage* facilities are a necessity. History has shown that negligence in finding adequate storage areas for equipment out of service, raw materials, intermediate products, solvents, by-products, specialized instruments, and spare machinery parts has led to cluttering of the pilot plant area, with resultant decrease in operating efficiency, loss of valuable materials and increase in hazards to personnel. An area equivalent to at least 30% of the pilot plant area, and preferably 50%, should be available for storage. Where large amounts of organic liquids are required, outside tank farms should also be provided.

The actual pilot plant working areas should occupy the major portion of the space in the building. Part of this area should be multiple-story space in order to provide sufficient head room for stills and vertical pilot plant installations. The amount of such multiple-story space should be carefully planned, for if it is not utilized the extra volume is useless. On the other hand, experience has shown that the fewer individual rooms there are in the pilot area the more flexible is the area. It is well, however, to isolate at least one room for dusty operations such as grinding, size separation, and packing.

A large three-story room with open balconies on the second and third levels has proved useful in practice. The balconies should occupy about 70% of the floor area. In some cases, open steel grating has been used on the balcony, but has not proved too satisfactory. Reinforced concrete floors with grating-covered slots, through which service and transfer lines may be run, appear more practical. Steel plate may also be used where drains are unnecessary.

Floor plans of one recently built laboratory are shown in figures III.95, III.96, and III.97. This particular laboratory makes use of steel grating for most of the second and third floors. All vertical columns are provided with punched holes for use in suspending piping and light equipment. Storage space is inadequate within the building, and for many purposes the open three-story area cannot be adequately used. An open three-story area only one bay in width would allow considerably more floor space. Such a bay is necessary to allow a traveling crane to run the length of the building, and is particularly valuable when heavy equipment must be handled. On the other hand, multiple-story pilot plants of considerable size can be built on steel framework which may be erected in the open area.

Various modifications of the above arrangement will suggest themselves upon study. The multiple-story space and the operating crane could run crosswise the building in the end bay or last two bays. In either case, the balconies could be offset so as to allow the traveling crane to deposit heavy equipment on any floor without the aid of a swinging jib crane.

SERVICES

Services common to the entire structure should include:

1. A controlled heating and ventilating system
2. At least one toilet, urinal, wash bowl and shower for every 20 people
3. At least 10 square feet of space for each locker occupant
4. A passenger elevator for buildings of three or more stories
5. A lighting system producing 30 to 35 footcandles in experimental areas, and 50 to 75 footcandles in offices and bench laboratories

Heating and Ventilating System: Adequate ventilation is a basic requirement of any pilot plant laboratory, inasmuch as the comfort and safety of personnel are dependent upon it. In large laboratory rooms the heating system can be integrated with the ventilating system. Such a system must be capable of maintaining the temperature of the pilot plant area at a pre-determined level (about 65°F) even in the coldest weather, and of completely changing the air in the area at least four times each hour. Under special conditions, the system should be adequate to change the pilot plant air fifteen times each hour.

A typical and suitable system for a three-story laboratory of approximately 600,000 cubic feet (160'0" by 82'0" by 45'0" high) is as follows:

1. Eight heaters with a capacity of 5,000 cubic feet /minute each, installed just under the roof, four on each side of the laboratory and equally spaced along the length of the laboratory. Air intakes are on the roof, and distribution ducts for heated air run from the heaters to the first floor. Louvers equipped with suitable air-flow regulators are provided in the vertical distribution ducts at each floor level. Air intakes are equipped

with filters, and can be adjusted by means of dampers to regulate the amount of air recycled. Normally, no recycle is employed in summer months and a maximum of 50% is recycled in extremely cold weather.

2. In the roof at the longitudinal center line of the building are four exhaust fans of a capacity of 10,000 cubic feet/minute each. These fans are operated continuously.

3. The system described is supplemented by a local fume and vapor exhaust system directed toward a specific area where fumes and solvents are likely to be concentrated. An exhaust system with a capacity of 2,000 to 4,000 cubic feet/minute with sheet-metal headers on the suction side, to which flexible tubing can be attached, is very useful for this purpose. The discharged air from the system should normally be washed in a rotary water scrubber.

Pilot Plant Service Utilities

Mechanical services for the operation of the structure as a pilot plant laboratory should consist of:

1. High-pressure steam supply headers
2. Well water or equal temperature supply headers
3. Soft water supply headers
4. Demineralized or distilled water system, or both
5. Fire water supply headers and branches
6. City gas supply header
7. Compressed air header
8. Condensate return header
9. Underground sewer and waste disposal system
10. Vacuum system
11. Electric power (440 v, 3-phase) distribution system
12. Electric power (110 v, single-phase) distribution system

Utilities distribution headers: Practically all pilot plant equipment units require the use of steam, water, air, and power. Accordingly, distribution lines should be so located as to allow an adequate quantity and quality of each utility to be furnished to all portions of the pilot plant laboratory with a minimum of service line changes and alterations as requirements in the various areas change. Permanent headers of adequate capacity furnished with a sufficient number of takeoffs should be installed for distribution of high-pressure steam, the various types of water available, air, and perhaps in special cases other utilities such as vacuum and refrigerated brine. The requirements of such a header system should be studied carefully and installed only if there is a real demand. Maintenance on unused lines may be greater than that on lines constantly in use. It is a rare laboratory, however, which does not have need for steam and water headers. The location of the headers should be such that they are convenient (for changes and maintenance), close to the point of use, and economical of space requirements. The most commonly used locations are close to outside walls, or just under the furthermost projection of balconies. The former is usually preferable.

Steam: The size of the steam header line depends, of course, on probable demand. In determining demand for this and other services, it is better to overestimate requirements than the reverse. Steam pressure in the header should be slightly higher than the highest demand pressure contemplated. For instance, if 150 psi steam will be required for some units, line pressure should probably be at least 160 psi. Takeoffs to equipment requiring steam of lower pressure can then be made through pressure-reducing valves as a part of the installation of individual pieces of equipment. Each header takeoff should be fitted with a valve as close to the header line as practical. It is also well to install several master valves in the header line so that the entire line will not have to be shut off for repairs. Headers should be pitched slightly toward their far ends and equipped with traps at those points. As an alternate, the header may be installed as a closed loop.

Water: The number and size of water lines depends upon the supply and price of water of varying hardness and temperature. Cold soft water must be available for condensers and coolers. In many plants two types of water are available, in which case economy may dictate two water headers in the pilot plant. Process demands for distilled or highly demineralized water will determine whether headers for these services are necessary. The number and location of separate fire lines feeding hose outlets and sprinkler systems must normally conform with insurance regulations or local ordinances. In any water system, pressure must be sufficient to supply an adequate amount of water at the highest point in the building. Hot water may be obtained easily at any given location by use of standard instantaneous heaters.

Electrical System: The electrical requirements for modern pilot plants can usually be handled by supplying 440 v, 60-cycle, 3-phase power for all motors of 1 hp and above, and 110 v, 60-cycle, single-phase power for motors less than 1 hp. The distribution of electricity will, of course, depend upon space arrangement within the building.

Because of the handling of solvents in most chemical pilot plant laboratories, it has become imperative that a great deal of the space be equipped with Class I Group D electrical equipment. When the pilot laboratory consists of one large multi-story room, it is not good practice to install explosion-proof equipment in one section of the room and standard equipment in another part. Even though the cost is greater, the entire working laboratory should be considered a hazardous area and Class I Group D equipment installed. Of course, when only a small percentage of the units handle flammable solvents, the explosion-proof area can be isolated in a separate room with concurrent reduction in the cost of electrical equipment. For the purpose of the present discussion, however, it will be assumed that the entire working area must be made explosion-proof.

The electrical system consists of a main switchgear and transformer room which can be locked and entered only by the designated electrical workers. A second room open to pilot plant operators will contain the building power distribution panel which will include magnetic starters, circuit overload relays, etc. Both of these rooms should be located in the service portion of the building outside the explosion-proof area.

Final electrical distribution can be made in the operating area from the columns therein. The suggested electrical equipment for each column is as follows:

1. Four plug-in receptacles (15 amp. each, 3-phase, 440 v).
2. Six plug-in receptacles (15 amp. each, single-phase, 110 v).
3. A distribution panel with 5 circuits (15 amp. each, 3-phase, 440 v) for the distribution of electrical power by rigid conduit connections.
4. A distribution panel with 5 circuits (15 amp. each, single-phase, 110 v) for distribution of electrical power by rigid conduit connections.

The general sequence for the plug-in receptacle power lines is as follows:

1. Circuit overload relay for each circuit in the power distribution room
2. A disconnect switch before and close to each receptacle
3. A starter adjacent to, or affixed to, the motor and equipped with a thermal-overload relay, sized by motor requirements

The general sequence for conduit-connected equipment is as follows:

1. Circuit overload relay for each circuit in the power distribution room
2. The distribution panel on each building column equipped with 5 circuits of 15 amp. each, 440 v, 3-phase, or 5 circuits of 15 amp. each, 110 v, single-phase. Each circuit to be equipped with a thermal-overload relay followed by a disconnect switch
3. Conduit connection from the cabinet to the motor starter which is adjacent to, or affixed to, the motor and equipped with a thermal-overload relay sized by the motor requirements

All motors, starters, switches, instruments, and similar equipment in an explosion-proof area must, of course, be of an approved totally-enclosed Class I Group D type. In some cases this requirement poses problems that can be solved only by great expense or by a decrease in efficiency. Electric clocks, for instance, are available in only a few sizes for Class I Group D areas. Electric heaters are seldom allowable. Explosion-proof telephones are cumbersome and expensive. The use of gas flames is, of course, not allowable. Explosion-proof traveling cranes are of special design and, accordingly, quite expensive. Many instruments are difficult to adapt to Class I Group D areas and must be specially made. In those cases where an instrument designed in accordance with the proper code cannot be purchased, it has been found permissible, with the concurrence of the underwriters and others concerned, to house it in an air-tight cabinet with a positive pressure of clean, fresh air, and to purge the cabinet at the rate of ½ cubic feet/minute per cubic foot of box capacity.

As a part of the electrical system, two general alarm systems will normally be required. These are:

Process Alarm System. It is desirable that the alarm system be integrated by means of a single panel equipped with a signaling alarm (sound is preferable) and suitable signal lights to indicate the source of the alarm. This panel can be used for tanks, the levels of which are higher or lower than a predetermined range, equipment overheating, and possibly an automatic explosive-vapor pick-up and analyzing system.

Fire Alarm System. This should be installed in accordance with the National Fire Protection Association's recommendations.

Air: Compressed air may be required for operating instruments, blowing filters, lifting acids, running air-actuated equipment, or for process. Whether or not one or several compressors should be used for this service depends largely on demand and quality requirements. Air for instrument and process must be clean and oil-free. The first-mentioned requirement is usually handled separately because the load is fairly constant and pressure fluctuations may be caused by a rapid draw at other locations. Hot air or dry air for special uses may be obtained by use of standard equipment containing heating coils or water vapor absorbents.

Gas: In pilot plant laboratories where gas requirements are high, a distributing header system will be necessary. The minimum pipe size to warrant such distribution is approximately 4 inches. Where gas is used in a pilot plant laboratory, it is obvious that any explosion-proof areas must be isolated by walls and air-lock doors. In some cases, furnaces may be handled as mentioned later under installation of spray dryers.

Vacuum: Pilot plant requirements for vacuum are seldom as great as the requirements for steam and water, so only in unusual cases will extensive header systems be needed. The number of units which can be handled by a header system is limited because of the enormous size that would be required for the header line. It is sometimes advisable to install a general system in one area, or along one side of the pilot room, to care for infrequent and changing vacuum requirements. The vacuum can be initiated either by steam-jet ejectors or vacuum pumps capable of producing a vacuum of

28 inches Hg where required. Specific pieces of permanent equipment such as evaporators, large stills, and dryers can, in many cases, be connected advantageously to their own individual vacuum sources.

Condensate Return: Decision to return all condensate from steam-heated units to the boiler house or various process stations depends upon its volume, value, degree of contamination, and problems of measurement. In many pilot plant installations, requirements for heat balances on various pieces of process equipment are such that condensate should be measured. Metering is difficult, and collection and weighing of condensate is often the simplest solution to the problem. Care should be taken in such cases to cool the condensate issuing from traps to avoid flashing and subsequent fog in the atmosphere.

At other times, when condensate is particularly valuable or volume high, a condensate return may be advisable. Such a system will require a header around the laboratory liberally equipped with plugged branches at several locations on each floor. The header can discharge into an accumulator below the first floor level, from which it may be pumped to the boiler station.

Waste Disposal: Wastes from pilot plants may be divided into several classes: insoluble wastes (e.g., gypsum, tars), soluble wastes (acids, caustic, dilute organic solutions), and noxious fumes. The liquids and solids are usually accompanied with fair quantities of water. It is assumed, of course, that sewage from toilets will be handled in an adequate sanitary sewage system.

Commonly, pilot plant wastes can be handled in the same waste disposal system that serves the manufacturing plant. It is only necessary, therefore, to deliver the wastes to this system. As mentioned in the general description of the building, open troughs covered with iron grating in each bay serve quite well in pilot plant laboratories where spills are usually greater than in manufacturing plants, and where many experiments are run in drums or small kettles and the contents dumped directly to the sewer. Drain pipes with plugged branches should be provided at balcony floor levels to deliver wastes from equipment in areas not equipped with open troughs. Because of the comparatively large amounts of solids which may be dumped, it is good practice to have a catch basin near the pilot plant laboratory so that the waste to the plant sewer system may be largely liquid.

Noxious fumes and vapors are often not considered as wastes, but actually they are, and means must be provided for their disposal. These fumes and vapors are often gathered by the exhaust system mentioned previously, in which case they may be passed through a wet scrubber and thence to the sewer system. Dust may be handled in the same manner. Occasionally, process fumes are in sufficient quantity that separate scrubbers must be installed to handle them.

In any event, the requisites of a pilot plant sewer system are that it deliver all pilot plant wastes as rapidly as possible and as free of solids as possible to an adequate disposal system. Flow through the system must be sufficiently rapid to prevent settling of solids in lines, and of sufficient size to prevent backup of wastes on the pilot plant floor. Cast iron pipe is normally adequate for sewers, except in those cases where large quantities of acid liquors must be handled, in which case "Duriron" or other corrosion-resistant metal or plastic-lined pipe must be used.

Acid and Alkali: In only the unusual case will sufficient demand for acid and alkali exist to warrant installation of a header system for distribution. In all laboratories, however, it is an awkward practice to handle very large quantities of corrosive liquors in carboys. In one pilot plant laboratory which comes to mind, three 1,000-gallon storage tanks are provided outside the laboratory for storage of sulfuric acid, hydrochloric acid, and 50% caustic soda solution. However, bulk deliveries of these materials in these quantities are not available in all locations. In this particular case, these materials are pumped to head tanks equipped with automatic liquid level controls, located on the third floor of the pilot plant building. When sufficient requirements for these acids or alkalies exist, the liquids may be piped by gravity to any part of the pilot plant laboratory by installing temporary lines. Consideration had been given to the installation of header lines from these tanks to all parts of the laboratory, but installation and maintenance costs could not be justified. The storage and head tanks for sulfuric acid and caustic soda solution are constructed of steel; the muriatic acid tank is rubber-lined. Pumps and lines for the remainder of the system are: "Durimet" pump and black-iron lines for caustic soda solution; "Duriron" pump and black-iron lines for sulfuric acid; and "Durichlor" pump and rubber-lined pipe for muriatic acid. For temporary distribution of these liquids from the head tanks, plastic pipe or hose may be used.

Refrigeration: As is the case with acid and alkali, most laboratories do not need header systems for distribution of refrigerated liquids; in a few cases such distribution may be warranted. Where it is warranted, insulated lines carrying refrigerated brine in a header system have been installed. In those pilot plant laboratories needing refrigeration only occasionally, a different treatment is advisable. An ammonia compressor and a tank of refrigerated ethylene glycol or like liquid can be installed in a comparatively small space. By fitting the tank of refrigerant with a pump it is simple to pipe refrigerant to a particular area by installation of temporary tubing. Systems of this type should be considered in equipping the pilot plant laboratory. In those cases where large amounts of ice or dry ice are used, special storage rooms should be provided. In still other cases, it may be necessary to provide one or more cold rooms, which normally should be provided with explosion-proof equipment because of the hazard of handling volatile solvents in poorly ventilated areas.

EQUIPMENT

The equipment for a pilot plant laboratory may be divided into two classes, general and special. General equipment includes that of a service nature used in all pilot plant studies (e.g. service tanks and shop equipment), and also equipment accessories such as pumps, instruments, and steam traps. Unfortunately, very little specific information can be given on this subject, because of the wide variation of process studies that are carried out in pilot plants. One has only to consider three industries, the natural gas industry, the ceramics industry, and the food industry, to see the lack of uniform equipment requirements, even of a general nature, for a general pilot plant laboratory.

The chemical industry per se probably makes more pilot plant studies than any other, so the equipment considerations which follow will be closely related to the requirements of that industry. Under special equipment will be discussed the equipment necessary to carry out studies on the more important chemical engineering unit operations and processes.

General Equipment

Few pilot plants will not require liquid feed in one form or other, i.e., solutions, slurries, or organic liquids, as raw materials or process additions. Accordingly, consideration should be given to the source of these materials and whether intermediate storage or pretreatment of a general nature is required. If so, general service tanks may be installed on the top floor of the building (for gravity flow and efficient space utilization) or on any other floor. Tank sizes will vary greatly from one laboratory to another, but ordinarily 500, 1,000, and 2,000 gallon tanks suffice. The tanks should be corrosion-resistant to the variety of materials to be handled. By installing an outside heat exchanger and a circulating pump with each tank, the contents may be preheated. For handling slurries, variable speed agitators have also been found useful. Only in unusual cases are distribution header lines desirable.

Other general equipment includes pumps, instruments, steam traps, scales, heat exchangers, condensers, shop equipment, valves, conveyors, and pipe. Because of the varying demands by different pilot plants, only a few general statements can be made.

In manufacturing operations, maintenance economy demands standardization of these general accessories. The economy of such standardization in pilot plants is doubtful. Accordingly, pumps of widely varying types (centrifugal, gear, and reciprocating) must be available. Stainless steel pumps are of widest general value, but special materials such as iron, bronze, glass, rubber-coated steel, nickel, and other materials will be required.

Pipe and tubing sizes should be limited as far as possible, but even so, a number of sizes will be required. The wide use of tubing is advisable to reduce the required stock of fittings. For ease of piping changes, flanged pipe or tubing with suitable fittings should replace pipe with screwed fittings as much as possible. It has been found generally advantageous to indicate by colored bands the type of material flowing through a given pipe or valve. Colored bands of cellulose tape circling pipes on both sides of valves have proved satisfactory.

At least one permanent floor-scale will be found useful. Such a scale should be of sufficient size to handle small four-wheel trucks carrying two 50-gallon drums.

Where condensate must be measured, bucket-type steam traps have been found superior to expansion traps.

Heat exchangers and condensers can be standardized fairly well and as few types as necessary will prove economical. Standardization of instruments is virtually impossible. Actually, the pilot plant should serve as much for proving of instrumentation as for any other purpose. Even so, it is recommended that all instruments be installed in panel boards. Instruments are costly, and if they are not handled with respect in the pilot plant, one cannot expect adequate care to be exercised in commercial installations based on pilot plant studies.

Shop equipment is fairly well standardized, and the types installed in research laboratory shops and plant shops will be found suitable. The variety depends on location and availability of other shops and the amount and type of work. If stainless steel equipment is to be welded in the shops, care must be taken that proper annealing facilities are available. The corrosion resistance of expensive stainless steel such as type 316 can be reduced almost to zero by improper welding methods or lack of care in annealing.

Portability of Equipment

The question of portable equipment vs permanently installed equipment always arises in outfitting a pilot plant laboratory. Small pieces of equipment such as pumps and kettles can be made portable, i.e., installed on a frame supported by casters, at a price. Such portability is desirable in saving labor and time, but it is often over-rated. Portable electric pumps should carry their own starting boxes and thermal protection. If the pump is to be used in an explosion-proof area (Class I, Group D, or Class II, Group G) conduit must normally be used for the electrical hookup, so portability is a doubtful asset. Tanks and kettles of 200 gallons or less capacity can usually be made portable, but larger tanks and kettles are too heavy, particularly when full, for ease of moving. The best way to provide portability in a pilot plant laboratory is by use of a good traveling crane, supplemented by small platform trucks. In the final analysis, portability depends on many factors inherent in the type of work contemplated, and is not too subject to generalities.

It should be remembered that portability of equipment is only one factor in the flexibility that is desired in a pilot plant installation. Other factors, each of which is of nearly equal importance, are: variable speed in agitators and other motor-powered equipment, suitability of equipment to a fair range of temperature and pressure operation, the use of hoses in place of pipe, ease of access to equipment for piping changes and equipment alterations, adequate header systems for distribution of utilities and process liquids, and provision of an adequate number of unions and valves in piping layouts.

Even so-called permanent equipment can be installed in such a way that it may be dismantled and moved with a minimum disruption of other work in progress. Concrete piers, pipe legs, or channel iron may be used for support and anchored to the floor with expansion bolts. A good practice in the installation of concrete piers is to pour the piers on paper rather than directly on the floor. In this manner the pier can be removed leaving only one or more expansion anchors in the floor. This facilitates removal of equipment without disfiguring the floor.

Special Equipment

Selection of operating equipment for pilot plant laboratories poses several questions: a. What pieces of equipment are in sufficient demand to be generally available in the laboratory? b. What is the proper size of such equipment? c. Of what material of construction should it be made? d. Should it be purchased or fabricated in the shop?

These questions may be generally answered as follows: Initial installations are usually governed by the particular projects under study or contemplated in the near future. Size of equipment is governed partially by availability and primarily by the smallest size, the results from which may be extrapolated to commercial operation. In cases where the pilot plant may be operated eventually as an interim production unit, equipment size should be sufficient to meet market development demands. In still other cases, minimum equipment size will be such that the smallest stream entering the process can be adequately measured and controlled.

For utility of operation, any piece of equipment should be constructed of such materials that it can be used for a wide range of process studies.

When standard equipment can be purchased, it is usually economic to do so because of lower initial cost, suitability to maintenance, and similarity to commercially-sized equipment (for added confidence in extrapolating data).

All equipment should be installed so that it is freely accessible on all sides. A good general rule requires 2-foot clearance on all sides of any installation, in addition to necessary working area. In many cases this means that extra supporting steel will be required to make the particular installation free standing. The extra initial cost can usually be justified by savings in operation.

The following discussion of equipment suitable for the most widely used unit operations and unit processes delineates the above factors.

Tanks, kettles, and batch reactors—An adequate supply of tanks and kettles of various types, sizes, and materials of construction is fundamental to good pilot plant practice. These vessels are used both for storage of liquids and for a variety of physical and chemical process studies. Tanks are freely available on the market in a number of designs, and built of a wide range of materials of construction. They are most commonly un-jacketed and built of wood, steel, stainless steel, plastic, or steel lined with rubber, enamel, or synthetic resins. The usual pilot plant laboratory requires a variety of sizes in several kinds of material. Wooden tanks are quite suitable for storage of water and a few corrosive solutions but must be kept filled at all times to prevent drying out. In some cases, cleaning presents a difficult problem.

Small tanks or stock pots on casters are extremely useful. Several types are available in stainless steel in various sizes from 5 gallons to 50 gallons capacity. Ordinary 55-gallon drums are also useful in cases of emergency. The upper size limit for portable tanks is about 200 gallons.

All vertical open tanks should be so outfitted that portable propeller-type mixers can be installed. A few of the larger tanks should be fitted with permanent agitators of the paddle, anchor, or turbine type.

Tanks may or may not be covered most of the time, but if not, covers should be available when necessary to minimize contamination of contents. For more or less permanent storage of liquids, horizontal tanks with side agitators are useful when floor space is available and head room is at a premium.

All tanks should be provided with bottom outlets and valves of sufficient size to carry away without plugging the most viscous slurries and solutions that may be used in the tank. Gate valves, Saunders-type valves, lubricated plug-type valves, and flush-bottom valves may be used. Globe valves are usually unsatisfactory. When the contents of the tank must be heated, the tanks may be jacketed, fitted with internal steam coils, or outside heat exchangers. The latter two methods of heating require smaller investments and allow a wider range of operating variables than do jacketed tanks. It is suggested that jacketed vessels be limited to kettles except in a few cases where jacketing of a tank is unavoidable. Live steam may be used efficiently at times for both heating and mixing.

Kettles are most valuable in the pilot plant laboratory for carrying out batch processes which require addition of heat, the carrying out of chemical or physical reactions in a confined space, or pressure and vacuum operations. For widest utilization, kettles should be jacketed, closed, and fitted with variable speed agitators and flush-bottom valves. An adequate number of openings should be provided in the top of the kettle in the form of nipples, man-holes, charging doors, bulls-eyes, and flanged openings, for charging and inspection of the kettle. Flush-bottom valves are particularly useful when the kettle is to be used for chemical reactions or solutions of varying density, because the "dead-space" inherent in the bottom outlet pipe when other types of valves are installed is eliminated. These valves often leak, however, so in some cases good practice dictates the installation of a second valve of the quick-opening plug type. For those operations, where occasionally a reaction "runs away", and further processing may be hazardous, quick-opening dump valves may be installed. The location of such kettles should be planned carefully and, in extreme cases, located over a pit or tank partially filled with water where the reaction may be "killed".

It is usually poor economy to install kettles with either jacket pressure or internal pressure limits very much lower than the maximum pressure of steam available for heating, up to about 150 pounds/square inch. Initial investment is somewhat higher but is counteracted by the flexibility of the unit. In a similar manner, variable speed agitators may be justified. It would be advantageous if each kettle could be equipped with interchangeable anchor-type and turbine-type agitators, as well as with adjustable baffles. This is seldom practicable, so good practice dictates different types of agitators in various kettles.

Kettles are available as standard equipment in a variety of shapes and sizes in stainless steels, copper, nickel, glass-lined steel, and special alloys. A number of fabricators are in a position to build special designs in "Hastelloy" and similar materials of construction. The most widely accepted vessels for pilot plant use are built of stainless steel and enamel-lined steel.

In many laboratories, pilot plant studies per se are carried out in small (10 to 100 gallon) kettles. The larger kettles (100 to 500 gallons) are used for interim production of new products, or for those studies requiring the processing of comparatively large quantities of raw material. The small kettle may be installed on dollies for portability; the large ones must be fixed. Large kettles are best installed on an upper floor level in such a manner that the manhole and charging opening are about 12 inches above the level of the floor. This allows maximum flexibility in handling the kettle product if it must be centrifuged, filtered, or further processed in other equipment. The installation should also be such that fractionating columns, condensers, receivers, and return lines can be installed with ease. In this manner, kettles can be used as stills, reactors, dissolvers, heaters, extractors, evaporators, and in similar installations. In those cases where kettles are to be used as crystallizers, it is preferable to provide a tilting mechanism, particularly if heavy magmas are expected.

In some installations it is advisable to furnish the kettle jacket with alternate heating and cooling media, such as steam, hot water, and cold water. This can be carried too far, however, with a resultant Christmas tree effect which may even hinder the operator. In many laboratories, one or more kettles is piped to receive hot oil or "Dowtherm" in the jacket.

Both the jacket and the inside of all kettles should be protected with approved pop-valves or rupture discs, depending upon the nature of the medium which will contact the safety device. Care must be taken to direct the blow-off vapors either outside the building or to an area where it is not hazardous to operating personnel.

Kettles operated above 250 psi (autoclaves) are usually not installed in general pilot plant areas. Operations of this type require separate structures where the autoclaves can be segregated behind protective walls (12-inch reinforced concrete). The roof and one side of such structures should be light in weight and located so that adjacent property is protected. On the other hand, in small-scale flow experiments in pipes where the amount of material in process is quite small, it is common to use pressures as high as 1,000 to 2,000 psi without special protective equipment.

Continuous reactors—The necessity of pilot plant studies in many processes is occasioned by attempts to render the process continuous. In work of this type the initial study is usually carried out in single tubes of small diameter, and later extended to multiple or larger diameter tubes. Such equipment is not standard and therefore, is beyond the scope of this presentation.

Agitators and mixers—Pilot plant requirements for mixing and agitating devices are probably broader than for any other unit-operation equipment. The wide range of viscosities, solubilities, and densities of materials which must be intimately contacted, in addition to the lack of any broad theoretical basis for mixer performance, makes the pilot plant the logical place for such studies.

Standard portable mixers in a variety of speeds and power requirements with interchangeable propellers of various pitches are available on the open market. A number of these mixers in stainless steel and "Monel" metal are a basic requirement in any pilot plant laboratory handling slurries or solutions in open vessels. It is good practice to furnish all closed tanks and kettles with permanent variable speed agitators. The distribution of anchor-, turbine-, and propeller-type mixers from one kettle to another depends largely on the type of material generally handled in the laboratory. One or more large tanks usually should be fitted with paddle agitators, supplemented by air or steam jets, for holding suspensions for further treatment.

In addition to portable propeller-type mixers, there is available from at least one firm an enclosed impeller-type portable mixer that may be used in an open 55-gallon drum for those reactions which require rapid dissemination of acid or alkali additions to solutions and slurries. These mixers are usually heavy and are best handled by a chain-fall attached to a mono-rail. Normally, turbine-type mixers are not portable because their performance depends to a great degree on the relationship between impellor design and the size and shape of the mixing vessel. Centrifugal pumps, however, may be used at times in place of turbine-type mixers.

The mixing of pastes and solids demands a variety of equipment, practically all of which is available in small-scale replicas of commercial equipment. Sigma-blade and Banbury-type mixers are available, jacketed and unjacketed, in various materials of construction, from one-gallon capacity up. Pilot plant data can be obtained readily in 10 to 20 gallon units; for interim production, larger units should be available. Pilot plant units should be capable of operation under either vacuum or pressure. Mixer blades are usually interchangeable. Best practice demands a motor drive of sufficient size to handle extremely viscous materials, even though the motor is far over capacity for the usually processed materials. These same comments hold also for the units listed below.

For the processing of solids demanding both crutcher and gate-type mixing with simultaneous mixing in two directions, "Dopp" kettles are available beginning with a 10-gallon size. For the mixing of plastics and pigments, flexible intensive mixers of the revolving muller and plow-type are available in various pilot plant sizes. Flexible ribbon-type blenders for the mixing of dry solids are also available in a wide range of types and materials of construction. It is an unusual pilot plant laboratory that will not find many uses for equipment of this type. Clearance between the ribbon-blades and the walls of the vessel should be quite close, and internal construction should be such that the unit may be washed, or even chipped out, with ease. Blenders suited to the introduction of liquids by means of sprays on to the surface of moving solid particles are often useful, but unfortunately are not always available on standard units.

In food pilot plants, vertical planetary mixers and various types of homogenizers are virtual necessities. Most equipment of this type is readily available in pilot plant size with interchangeable accessories from which the performance of commercial equipment can usually be predicted.

Centrifuges—In recent years, manufacturers of the various types of centrifuges have started production of pilot plant models of centrifuges from which commercial operations can be predicted.

Vertical suspended basket centrifuges are readily available in sizes as small as 12 inches in diameter, but there is doubt if centrifuges of this type less than 24 inches in diameter are suitable for determining spinning cycles and wash characteristics. One manufacturer is marketing a 24-inch vertical suspended centrifuge with a hydraulic drive that can be operated at any speed up to 2,500 rpm. The basket is removable for interchange of perforate and imperforate baskets. This flexibility is quite valuable in pilot plant work.

Horizontal continuous solid bowl centrifuges, disc-stack centrifuges, and automatic cyclic horizontal perforate bowl centrifuges of considerable flexibility, are all available in pilot plant sizes. Most can be built of type 316 stainless steel which is suitable to a wide range of process conditions. Centrifuges should be permanently installed on sound foundations which, in many cases, should be free of the building frame and floor. The use of rubber pads and spring vibration absorbers is conducive to smooth operation. The wide variation of separation and clarification problems that may be tried in the pilot plant requires motors suitable for very high starting load. Fluid couplings have proved quite useful for this purpose. If volatile solvents are to be used, the extra expense of proper vents appears justified.

All permanently installed centrifuges should be set sufficiently high to allow gravity flow into tanks of adequate size for the various discharging streams.

Crystallizers—Unless crystallization problems of a major nature are foreseen, kettles may serve adequately for the pilot plant study of this unit operation. In special studies, vacuum crystallizers and various other continuous crystallizers are available in pilot plant models. Stainless steel is the preferred material of construction for such units.

Stills and columns—Kettle assemblies in which one kettle acts as a still pot and another as a receiver are used quite widely in process development work. It is well, therefore, to install several kettles equipped with packed columns and condensers. Such units are usually made of stainless steel or are glass-lined, in which case they have rather wide versatility. The total area of the condenser in square feet usually approximates one-half the capacity of the still pot in gallons. Receiving kettles need be only three-fourths the capacity of the still pot.

For design work, adequate data can usually be secured in laboratory-scale glass columns. These should be installed in curbed troughs in a special room so that breakage may limit any resulting hazards to a small area.

Larger metal columns (copper, nickel, stainless steel, or glass-lined steel) require multiple-story head-room for installation. If such columns are supported by their own structural steel framework, they are more stable and accessible than if tied to existing building columns and beams. Fractionating columns can be made quite versatile by adequate instrumentation, multiple feed inlets, and variable reflux ratio controls. They should be insulated and normally at least 10 inches in diameter for good performance. Packed columns are usually preferred in chemical pilot plants; the need for bubble-plate columns will be obvious in special instances.

In petroleum refining work, where distillation is such an integral part of the process, it is often necessary to supply continuous fractionation equipment in conjunction with integrated pilot plants in order to make the product and to provide streams for recycling. In one laboratory, various sized columns for precise fractionation are installed, which columns may range in size from 20 to 200 equivalent plates. Because of capacity factors, these columns range from one inch to six inches in diameter.

Vacuum stills and columns present special difficulties concerning which few generalities can be stated.

Filters—Of all pilot plant equipment, more standard models of filters are available than for any other unit operation.

Continuous rotary vacuum filters are available in various diameters, closed and open, variable speed, variable depth of submergence, with and without precoat facilities, fitted with a variety of washing and cake discharge devices, and built of several materials of construction. The small 12″ by 12″ models give some indication of commercial performance, but the 3′ 0″ by 1′ 0″ models are required for accurate extrapolation of data. The larger units are not easily made portable, and should be installed in conjunction with sufficient feed tanks and product vessels for independent operation.

Pressure filters are available in an extremely wide variety of types usually built of stainless steel. Most units are portable and can be used in whatever portion of the laboratory demand dictates.

Very small plate and frame filters (6″ by 6″) can furnish reliable clues to many filtration problems, but where cloth life, wash and dumping cycles must be determined, a 30-inch press is indicated for good results.

Batch vacuum filters of the Buchner type are quite useful in preliminary production studies. Both stoneware and stainless steel filters are available; the former is the more versatile, but breakage is usually high.

Dryers—Like filtration equipment, many standard models of drying equipment, some portable and some not, are available. The smallest available sizes adequate for pilot plant studies, and with the degree of flexibility required for various types of drying equipment, are listed below:

Horizontal rotary atmospheric dryers—These are available in steam-tube, and preheated-air or flue-gas types. Portable units 8 feet long and 12 inches in diameter are suitable for pilot plant use. For effective use, they should be designed for variable drum speed and variable pitch and ease in changing from parallel to countercurrent flow. Vent stacks should be furnished with bag filters to reduce the dust nuisance. Several special designs in which air is introduced through louvers at various points along the length of the dryer are also available.

Spray dryers—Several companies make so-called pilot plant spray dryers ranging from 2½ to 4 feet in diameter. These units are in reality laboratory spray dryers and results indicate only whether or not a given material can be spray-dried easily, and the approximate appearance of the product. It is doubtful if good engineering data can be obtained on any spray dryer less than 11 feet in diameter, and then the data are reliable only for the particular type of dryer studied. A flexible pilot plant spray dryer in which different types of atomization and various types of air flow could be studied would be very expensive. At the present state of the art, therefore, it is doubtful if a pilot plant spray dryer should be installed in a pilot plant laboratory building. Because of their size, certain types of laboratory spray dryers are often installed in the pilot plant laboratory because sufficient space is not available in the research laboratory.

When a spray dryer or any other type of dryer requiring a furnace is installed in an explosion-proof location, certain precautions must be observed. In one case, a furnace house is built adjacent to the pilot plant laboratory and the hot gases to various dryers are piped through the laboratory walls.

Flash dryers—The smallest standard flash dryer requires head-room equivalent to two stories and must be permanently installed. By use of variable speed drives and several alternative means of air heating, the unit can be made quite flexible for pilot plant work.

Roll or drum dryers—Several standard models of roll dryers with single, double, or twin rolls, variable speed drive, variable steam pressure, interchangeable rolls, pendulum, splash, or dip feed, and suitable for either vacuum or atmospheric operation, are on the market. Small units with 6″ by 6″ rolls can be made portable, but are useful only in laboratory studies. For pilot plant work, the minimum size for reliable data is 24″ by 24″. Even so, experimental work on commercial-size rolls is usually necessary for good process design data.

Continuous belt dryers—One manufacturer of continuous belt dryers makes a pilot plant model which is said to give reliable engineering data for extrapolation to commercial units. The same data can probably be obtained more cheaply in static laboratory equipment.

Tray Dryers—Atmospheric tray dryers or cabinet dryers are very useful for the batch drying of experimental lots of granular materials, and for small-scale production. They are not particularly useful for securing engineering data. Both electrically and steam heated units are available, but the former are difficult to modify for use in explosion-proof quarters. Design varies considerably, and some types are far superior to others in air distribution and recycle control. In many cases the addition of a pre-dryer for entering air renders the unit much more useful. Small pre-dryers for air, using either activated alumina or silica gel, are satisfactory. Vacuum tray dryers come in a variety of sizes and are useful primarily for the drying of small lots of heat-sensitive materials.

Experimental drying rate units—Many experimental dryers have been described in the engineering literature. These units allow great flexibility and control of air rate, humidity, temperature and direction in the drying of solids in comparatively small amounts. Drying rate curves obtained in equipment of this type will greatly simplify pilot plant operations. The pilot plant laboratory is the logical place for its installation.

Vacuum rotary dryers—This term is somewhat misleading, inasmuch as the dryer shell is stationary and the only rotating element is a ribbon mixer within the shell. Units of this type are usually jacketed for heating with steam and are connected to a vacuum source through a wet or dry collector, condenser and receiver. Although built primarily as dryers, the small 2′ 0″ by 2′ 0″ units are useful for many unit-operation studies including extraction, steaming, evaporation, simple distillation, reaction, blending, and crystallization, as well as drying. In fact, the unit can be considered a horizontal jacketed kettle with a variable-speed ribbon mixer.

Other types of dryers—The more recently developed types of drying, such as infrared and freeze drying, are specialities not yet of general pilot plant interest.

Evaporators—Simple evaporation studies for process development can usually be carried out in jacketed kettles. Where continuous operation simulating industrial operations is required, specially designed pilot plant evaporators may be used. One such standard unit with a feed rate of approximately one gallon per minute (larger units are available) is so designed that four alternate types of evaporation may be studied, e.g., standard calandria, forced circulation, long tube rising film, and falling film. The unit may be changed from one type of evaporator to another in a short time, and the standard central downtake calandria can be replaced with an annular downtake unit without too much difficulty. The unit can be built of any common metal.

Mills—The mills installed in a general pilot plant laboratory are usually of only a sufficient variety to handle the type of raw material and product expected in a given laboratory. The units are seldom set up to allow the gathering of capacity data and power requirements, but rather as qualitative tools to produce a certain degree of comminution of a solid without reference to unit operations data. This is true, chiefly, because mill manufacturers have their own test equipment and methods of extrapolation, all of which are freely available to prospective equipment purchasers.

The particular variety of sizes and types of mills to be installed will vary so greatly from one laboratory to another that choices will not be discussed here. In most cases, however, all mills should be isolated in a specific room designated for milling, screening and similar dusty operations. Some of the smaller mills will be portable, whereas others must be installed on solid foundations. Normally, all mills should be installed sufficiently high above the floor to allow the product to be caught in a portable vessel or cart. To reduce dust a separate exhaust hood system should be installed over all permanent mills and over an area set aside for portable mills. This exhaust system should lead to some type of wet cyclone collector.

Extraction equipment—Liquid-liquid extraction problems are commonly studied on a pilot plant scale in vertical columns which may be installed in the same manner as distillation columns. The leaching of solids can be carried out in kettles and tanks or in filter presses. One vendor of countercurrent decantation systems manufactures a small 3-stage system, made up essentially of 300-gallon stainless steel tanks, which has been found useful in pilot plant practice. Another manufacturer of glass-lined equipment makes a modified extractor of the Soxhlet type, which is useful in extracting plant products.

Safety equipment—The pilot plant laboratory, like any other industrial building, should be furnished adequately with fire extinguishers, fire hose with nozzles, masks, fire blankets, eye fountains, showers, protective clothing, stretchers, and other safety items. The recommendations of the National Safety Council, the National Fire Protection Association, and Underwriter's Laboratories cover the minimum requirements for such equipment, and should be followed.

In most pilot plant laboratories, construction work is always going on adjacent to operating areas. Accordingly, the laboratory should be generously supplied with stands, rope, and warning signs to isolate the construction area. All large tanks and kettles into which maintenance men may enter should be so installed that agitator switches may be locked, and charging lines blanked off. All service equipment, such as ladders and hose, should be selected with safety requirements in mind.

Part IV

CONCISE DESCRIPTIONS OF SOME MODERN LABORATORIES

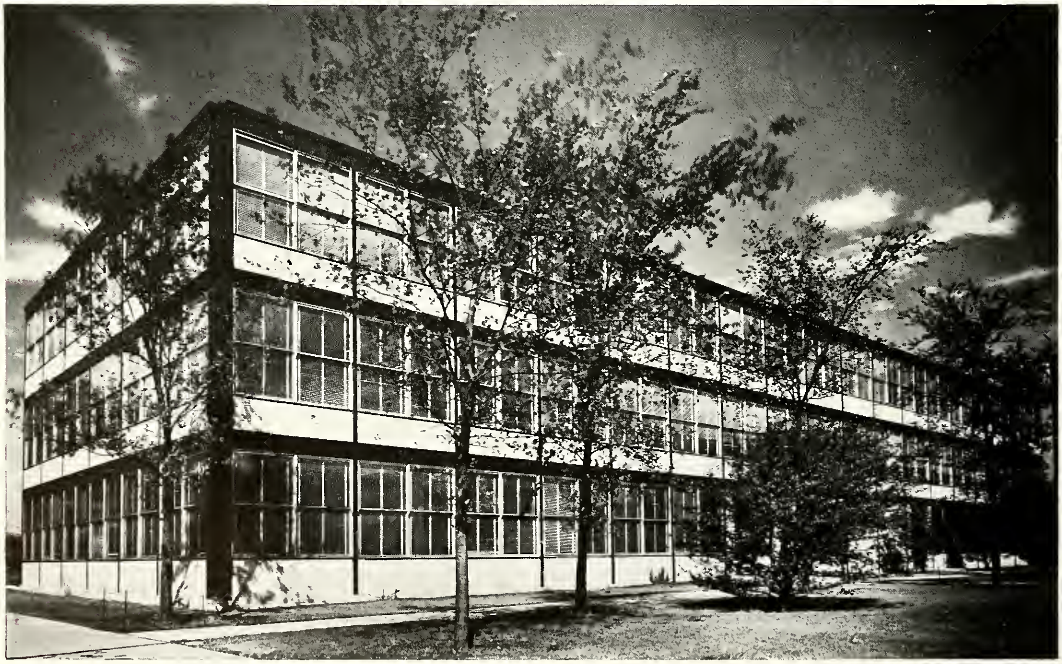


Figure IV.1 The Chemistry Building of the Illinois Institute of Technology, completed in February 1948, was the first modern academic and laboratory structure brought into full operation in the Institute's 100-acre campus development program. Providing over 60,000 square feet of space, it contains only two classrooms, the remaining space being devoted to laboratories. The three-story building is located at 33rd and Dearborn Streets, Chicago.

1

ILLINOIS INSTITUTE OF TECHNOLOGY LABORATORY

Martin Kilpatrick

Illinois Institute of Technology, Chicago, Illinois

The Chemistry Building on the campus of the Illinois Institute of Technology is one of the most recent structures in that school's current building program. The project, when finished, will offer one of the few completed group developments by an internationally known contemporary architect—Mies van der Rohe.

In a technological institute the demands upon the space are so changing that early in the development of the project it was decided a steel skeleton structure would offer the greatest flexibility of room arrangement. As the columns and beams carried the loads the walls were no longer called upon to serve their more conventional purpose of bearing, hence they could be installed or removed as the space demands dictated. It was found by study that a 24'0" by 24'0" bay system provided the most desirable space for offices, classrooms and laboratories. It is this 24-foot module that coordinates the planning of the entire campus.

The logical extreme to which Mr. van der Rohe has carried the use of the skeleton results in an architecture which is original, strong, simple and meticulous in the refinement of its detail. The steel columns, normally visible, are covered with concrete to conform to city fire codes. The outer surface of the building, the skin—so to speak—passes in front of the columns, thereby shielding the fireproofing from the elements. This skin, partly brick, partly glass, is supported by steel mullions which occur in front of the columns and also at midpoints between. To clarify the fact that they are not a part of the steel skeleton but are hung from the skeleton and only provide a structure for the stability of the skin, the mullions are stopped a few brick courses above the ground.

This insistence on differentiating between structure and nonstructure, between one element and another, between one material and another, characterizes, in part, the spirit in which the chemistry building and all others on the campus were created. Except in rare instances it is a spirit not fully manifested since the Gothic.

DIVISION OF SPACE

The chemistry building, shown in figure IV.1, is a 218'0" by 74'0" rectangle. With basement and three floors, it affords just over 60,000 square feet of space. This means in terms of the 24-foot module a width of three units and a length of nine units, each "unit" being 24'0" by 24'0", or 576 square feet.

The objectives were to provide space and research facilities for twenty staff and seventy full-time graduate students, and instructional facilities for one hundred or more undergraduate majors in chemistry, as well as service courses in chemistry for chemical engineers,

TABLE IV. 1

	Number of Units				
	Basement	1st	2nd	3rd	Total
Undergraduate laboratories			17	5	22
Graduate research laboratories		9		14	23
Auditorium	6	6			12
Demonstration preparation room	1				1
Classroom		1½			1½
Conference room				½	½
Shops	6				6
Storerooms	4	1	1	½	6½
Machinery room	2				2
Offices		1¾	3½	½	5¾
Student locker room	3				3
Washrooms		1	1	1	3
Corridors and stairwells	5	6¾	4½	5½	21¾
	27	27	27	27	108

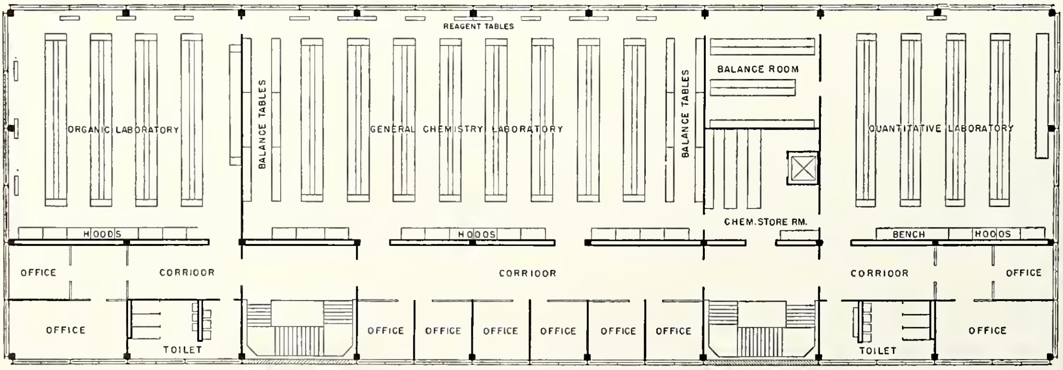
metallurgical engineers, food technologists, biologists, biochemists, physicists, fire-protection engineers and home economists. In addition, it was necessary to provide a course in general chemistry for civil, electrical and mechanical engineers.

The space in the building, as allocated by units, is distributed as shown in Table IV.1.

UNDERGRADUATE LABORATORIES

The whole of the second floor is devoted to undergraduate instruction, with eight units for general chemistry and qualitative analysis, five units for quantitative analysis, and four for organic chemistry. Figure IV.2 gives the floor plan. The laboratory furniture is the conventional built-in equipment with the services provided under the shelf above the trough as illustrated in figure IV.3. This photograph shows the freshman laboratory, which has 1152 lockers, with nine lockers per working space. The quantitative and organic laboratories are built along similar lines, but with larger individual lockers and with services such as steam, vacuum and compressed air in addition to the gas, water, distilled water and 110-volt AC electricity which are supplied at the laboratory table in the freshman laboratory. The quantitative laboratory is designed for sixty students at a time and can accommodate a total of 180; the

Figure IV.2 Second floor plan, Chemistry Building, Illinois Institute of Technology.



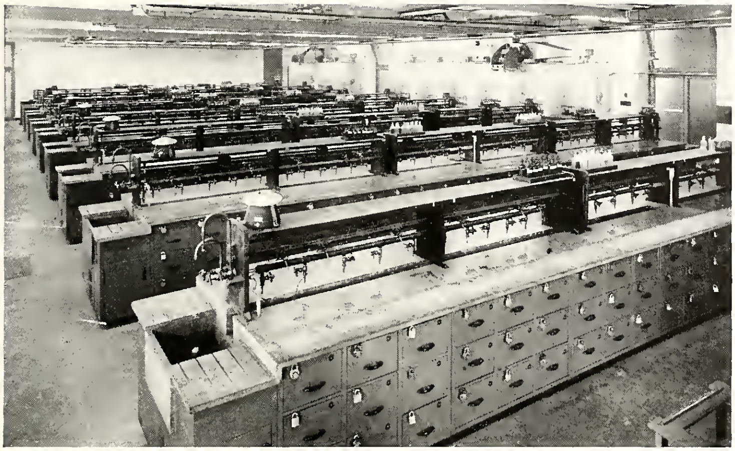


Figure IV.3 Freshman chemistry laboratory.

organic laboratory will take forty at a session, with an over-all capacity of 240.

On the third floor, the undergraduate physical chemistry laboratory, partly shown in figure IV.4, incorporates more distinctive features. The view of a corner of this laboratory shows a part of one of the four laboratory units, with services supplied at turrets, and a built-in thermostat. Practically the entire tabletop is available for experiments, and the view across the room is unobstructed. The lockers, numbering 128, are assigned to the experiments rather than to individual students so that, if necessary, two hundred students can be scheduled per week, with forty students at a session.

GRADUATE RESEARCH LABORATORIES

In planning the research laboratories, the aim was to obtain maximum flexibility at minimum cost. To accomplish this, services are provided by means of service strips—wall, center and island. Laboratory tables, vacuum racks, and other equipment are moved up to these service strips in accordance with individual research needs, and as the needs change other arrangements are readily possible. Figure IV.5 shows a center service strip providing 110- and 220-volt, single-phase; 110-volt, 3-phase; 110-volt DC; gas, air, water, steam, vacuum, distilled water and drains. A stone sink is

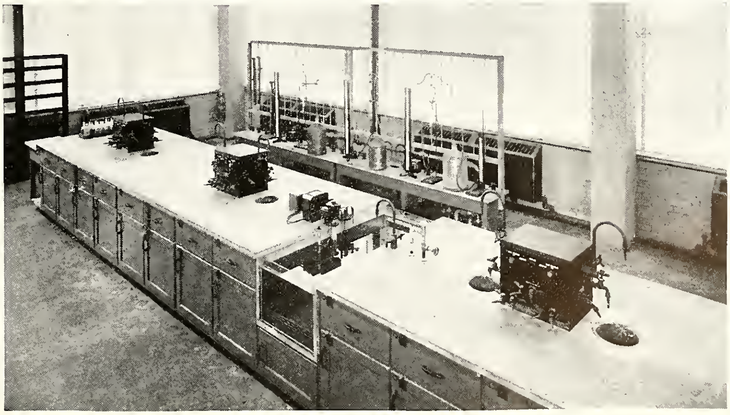
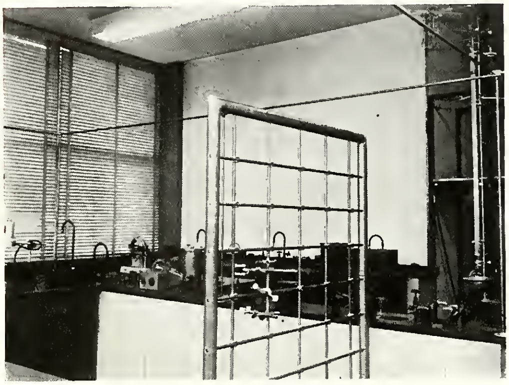


Figure IV.4 Corner of the Undergraduate Physical Chemistry Laboratory.

Figure IV.6 Portable vacuum racks and island service strip.

Figure IV.5 Research Laboratory, showing center service strip.



located at one end of the strip. All waste pipes and drains are of "Duriron".

The idea of flexibility is carried further by the use of vacuum racks on wheels. In figure IV.6 details of the leg lift can be seen, and an island service strip is shown behind the second rack. It is possible to move a vacuum set-up, constructed mostly of glass, to another location and still have the rigidity of a built-in vacuum rack. The over-all dimensions of the racks were determined by the size of the elevator, to provide complete mobility from floor to floor and laboratory to laboratory. A view of portable racks mounted with vacuum lines, as used in the instrumentation laboratory, is given in figure IV.7.

Figure IV.8 shows an organic research laboratory with hydrogenation equipment at the left and a canopy hood in the background. Most of the research laboratories are equipped with conventional type hoods with safety glass, exceptions being the canopy hood shown here and a walk-in hood with safety glass windows in one of the physical chemistry research laboratories.

All laboratory tables and equipment, with the exception of the service strips (with sinks) and hoods, can readily be removed from the laboratory as the changing nature of the research may require.

The research laboratories vary in size from one to four units, accommodating from four to sixteen research workers. This means there are no one- or two-man laboratories, which is a disadvantage of the 24-foot module.

CLASSROOMS

As the new metallurgical and chemical engineering building adjacent to the chemistry building provides suitable classrooms for instruction in chemistry, only one classroom and an auditorium were included in the chemistry building. The auditorium, with a capacity of 359, has a projection booth and a lecture demonstration table complete with services including a small table hood. The two wings of this table are mounted on wheels to permit setting up of demonstrations in the adjacent preparation room while the auditorium is in use. The classroom, with 70 fixed seats, is also designed for demonstrations and is equipped with dark shades and a projector.

Staff meetings, small seminars and oral examinations are held in the conference room.

SHOPS AND SERVICES

The shop area is divided into four sections, two units each being assigned to the mechanics' shop and glassblowing shop, one unit to the student machine shop and another unit to storage.

The basement storeroom of four units supplies—by elevator—the smaller dispensing storerooms on the second and third floors.

All services for the building originate in the machinery room in the basement and are brought up through a hollow wall between the main corridors and the laboratories. The building is heated by hot water, and entering air is tempered by heating coils installed in the intake ducts.

COST OF THE BUILDING

The building, which was contracted for during the period of O.P.A. control, was completed in 1948, and the cost breakdown is approximately as follows:

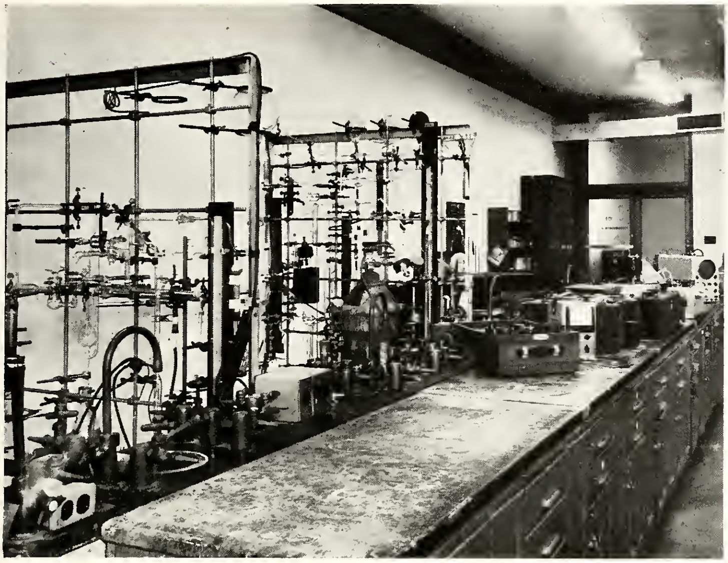


Figure IV.7 Instrumentation Laboratory. Vacuum racks are in use alongside the service strip.

Building

Cost, including the shell and the usual installations such as heating system (exclusive of steam supply), ventilation, ordinary plumbing, etc.	$715,000 (approx. $0.90/cu.ft.)

Facilities

Cost of laboratory tables, plumbing and electrical fixtures, hoods, blowers, vacuum pumps, compressors, etc.	$201,000
Cost of installation of facilities	$ 77,000
Miscellaneous costs	$ 10,000
	$1,003,000

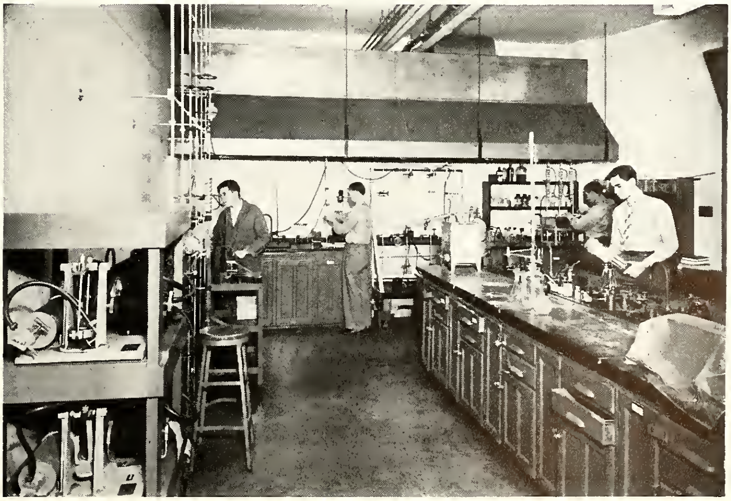


Figure IV.8 Organic Research Laboratory, with hydrogenotion equipment ond canopy hood.

2

NORTHWESTERN UNIVERSITY LABORATORY

V. C. Williams*

Northwestern Technological Institute, Northwestern University, Evanston, Illinois

Northwestern Technological Institute, designed by the architectural firm, Holabird and Root, is located near the north end of the Evanston, Illinois, campus of Northwestern University. The building faces Sheridan Road while the rear adjoins the shores of Lake Michigan. In addition to the four departments of engineering (chemical, civil, electrical, mechanical) the building contains the physics and chemistry departments of the College of Liberal Arts. Each department is, in effect, housed in a wing of the building which in plan is shaped like two letter E's placed back to back and joined by a large central structure (see figure IV.9). The wings are each three stories high, while the backs of the E's and central structure are four stories high. Additionally the west central structure has a fifth story which extends into the two towers at opposite ends of this section. The back of the south E has a full sub-basement.

The entire building is of reinforced concrete construction. Foundations are of the spread footing type which are typical of this locality with footings varying in size up to a maximum of 21'0" by 25'0" although the more usual is 10'0" by 10'0". Because of subsurface conditions lower footings are larger. Piling is used only under sections in the civil engineering wing which carry the 1,000,000 and 5,000,000 pounds test machines. The normal live floor load factor for the building on a basic module area of about 18'0" by 20'0" is 150 pounds/square foot for a 6½-inch pad thickness. Many sections, however, have higher floor factors where the required loads are greater. This is especially true in the civil engineering section where loads to 250 pounds/square foot are permitted. All exposed concrete flooring in the building was treated, after curing, with two coats of magnesium fluosilicate solution (2 pounds/gallon of water—1 gallon of solution/200 square feet). Recently the exposed flooring has been additionally sealed with one coat of a tung oil sealer. The results of this over-all treatment have been good. In the chemical engineering unit operations laboratory the resulting water repellency has been especially noteworthy. Texture floors were cast and ground to give full rounded corners in all toilet and shower rooms. The texture floor in the civil engineering department was achieved with a pea gravel topping which was then ground to expose the aggregate.

The contractor took special care in the casting of flooring because the concrete would be exposed on the lower side as the ceiling of the rooms below. The smooth finish obtained takes paint readily. In the various rooms all service piping to the area above is carried on the ceiling. This is in accord with the basic idea of extreme internal utility. Walls of offices are plaster on clay tile partitions which can be cracked out or installed as desired to open or confine new spaces. In corridors (see figure IV.10) "Vitricotta" tile is used and doors can be readily installed in this relatively movable material. The entrance foyer is finished in a pleasing combination of dark green Virginia greenstone floors and columns with pin-grain Appalachian white oak panelling. The decorative panels of a technological theme in the foyer are of Winona "Travestine" and were designed by Edgar Miller. This artist also conceived the panels in the main entrance. Window mullions are cast iron flame-sprayed with lead on zinc. All windows are steel casement type with inside bronze fly screen. A few offices in the administration section of the building are fully decorated as compared to the Spartan tone of the usual offices.

The main auditorium is directly off the entrance

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* Present address: General Aniline and Film Corp., Easton, Pennsylvania.

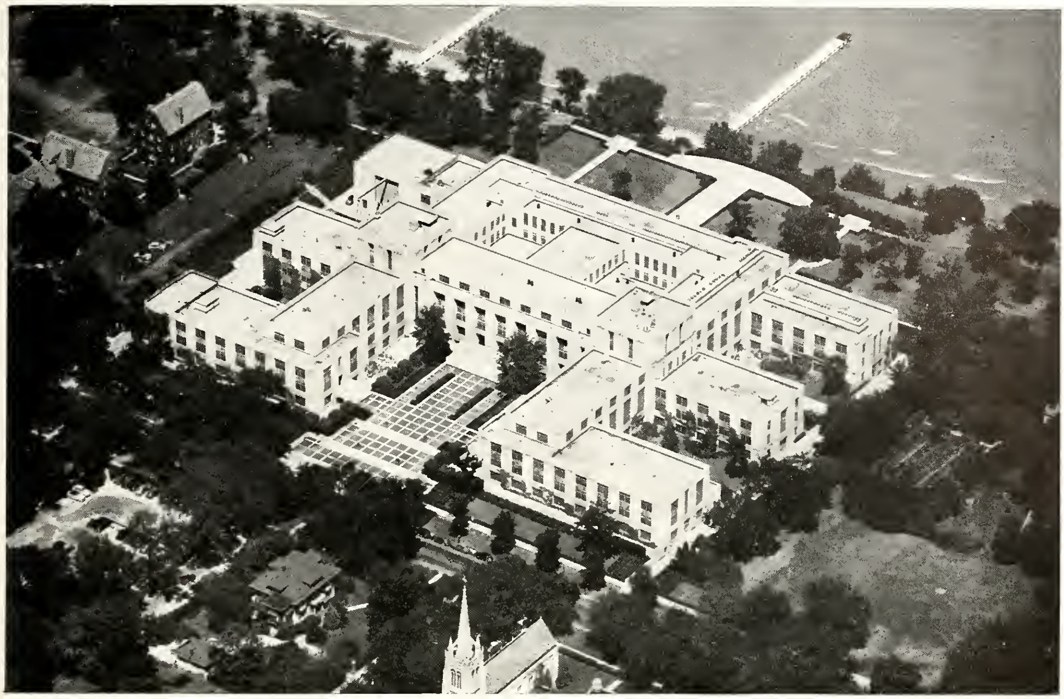


Figure IV.9a Aerial view of Northwestern Technological Institute Building, Evanston, Illinois (Hill Photo Service).

foyer. This auditorium, the large lecture rooms (e.g. Lecture Room 3, figure IV.11), and the library (figure IV.12) again use the oak to achieve a decorative finish and pleasing quality. In general, these are the fixed spaces which have had their functions set by final decoration. Otherwise, the building is a flexible, utilitarian, well serviced space which may be changed rather readily by economical wall shifts. The exterior of the building is finished in Lannon stone set in a random nonrepetitive pattern.

The plan of the building is shown in figures IV.9b to figure IV.9f. The areas of each division are given in Table IV.2.

TABLE IV. 2

Floor Areas By Divisions

	Area in square feet	
A. Civil engineering	50,000	
B. Mechanical engineering	45,300	
C. Electrical engineering	40,500	
D. Physics	53,000	
E. Chemical engineering	35,000	
F. Chemistry	90,800	
G. General spaces	25,800	
G. Lecture rooms	57,100	
G. Equipment and fan rooms	15,000	
G. Transformer vaults	1,800	
G. Towers	9,000	
	423,300	square feet
Approximate building volume	5,100,000	cubic feet
Corridors	6,300	lineal feet

DEPARTMENT DESCRIPTIONS

Administration

The administrative functions of the Institute are those dealing with engineering and building administration (the Dean and his direct assistants and staff), student affairs and registration, industrial relations and student placement, classrooms, lecture rooms, library, graduate students in engineering, research coordination, purchasing, receiving, shipping, and building services which include supplies, photostat and blueprint service, projection booths, maintenance, fire squads, and so forth. All the latter features of building services are in addition to the routine job of operating and servicing a building having just under ten acres of floor space. Total services to be cared for are listed in the Appendix.

The chief administrative officer of the Institute, the Dean, has offices (figure IV.9c) located in the west central structure on the second floor. Concentrated near these offices are the industrial relations department,

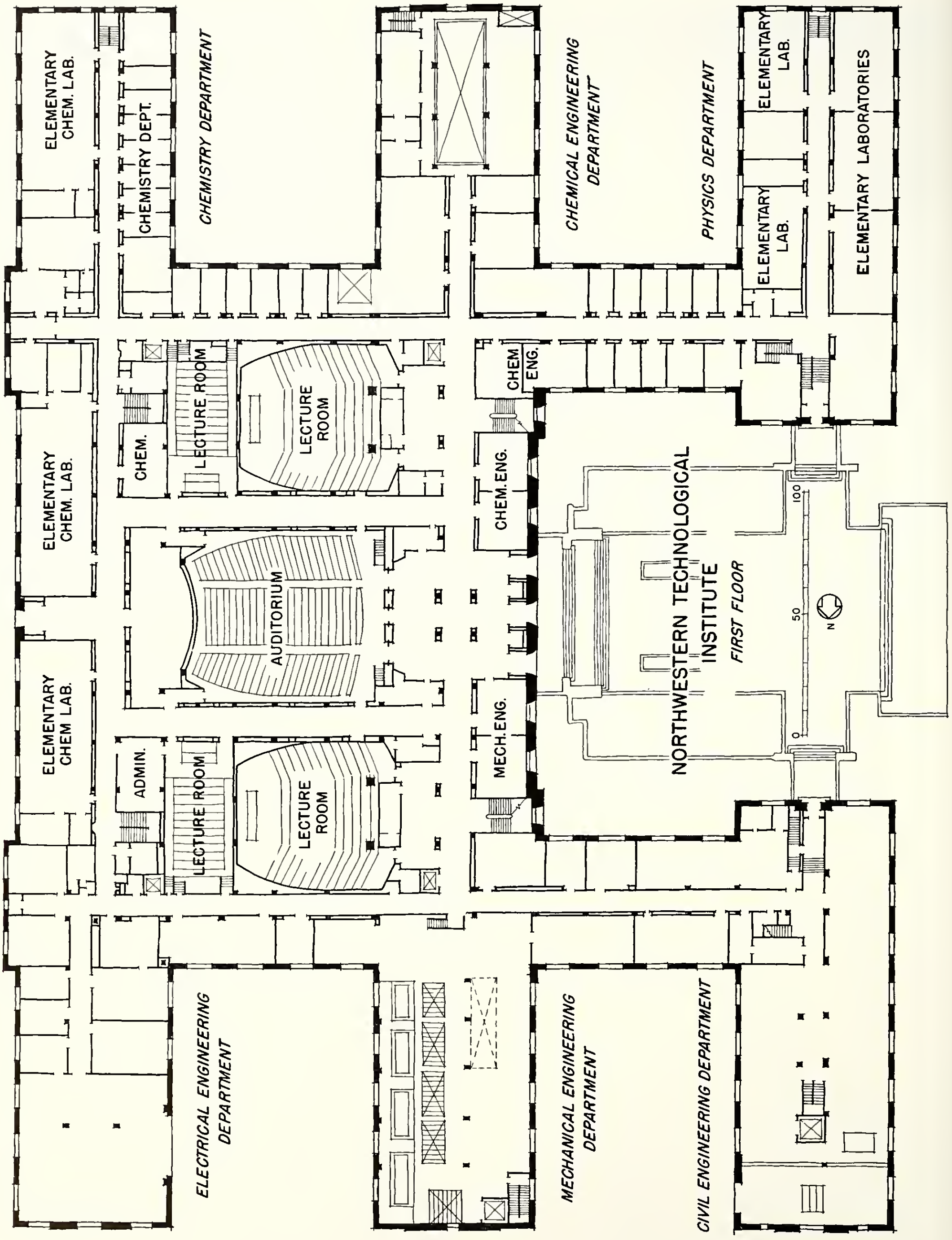

ELEMENTARY CHEM. LAB.
CHEMISTRY DEPT.
CHEMISTRY DEPARTMENT
CHEMICAL ENGINEERING DEPARTMENT
PHYSICS DEPARTMENT
ELEMENTARY LAB.
ELEMENTARY LAB.
ELEMENTARY LABORATORIES
CHEM. ENG.
LECTURE ROOM
LECTURE ROOM
CHEM.
ELEMENTARY CHEM. LAB.
CHEM. ENG.
AUDITORIUM
NORTHWESTERN TECHNOLOGICAL INSTITUTE
FIRST FLOOR
100
50
0
N
ELEMENTARY CHEM LAB.
ADMIN.
LECTURE ROOM
LECTURE ROOM
MECH. ENG.
ELECTRICAL ENGINEERING DEPARTMENT
MECHANICAL ENGINEERING DEPARTMENT
CIVIL ENGINEERING DEPARTMENT

Figure IV.9b.

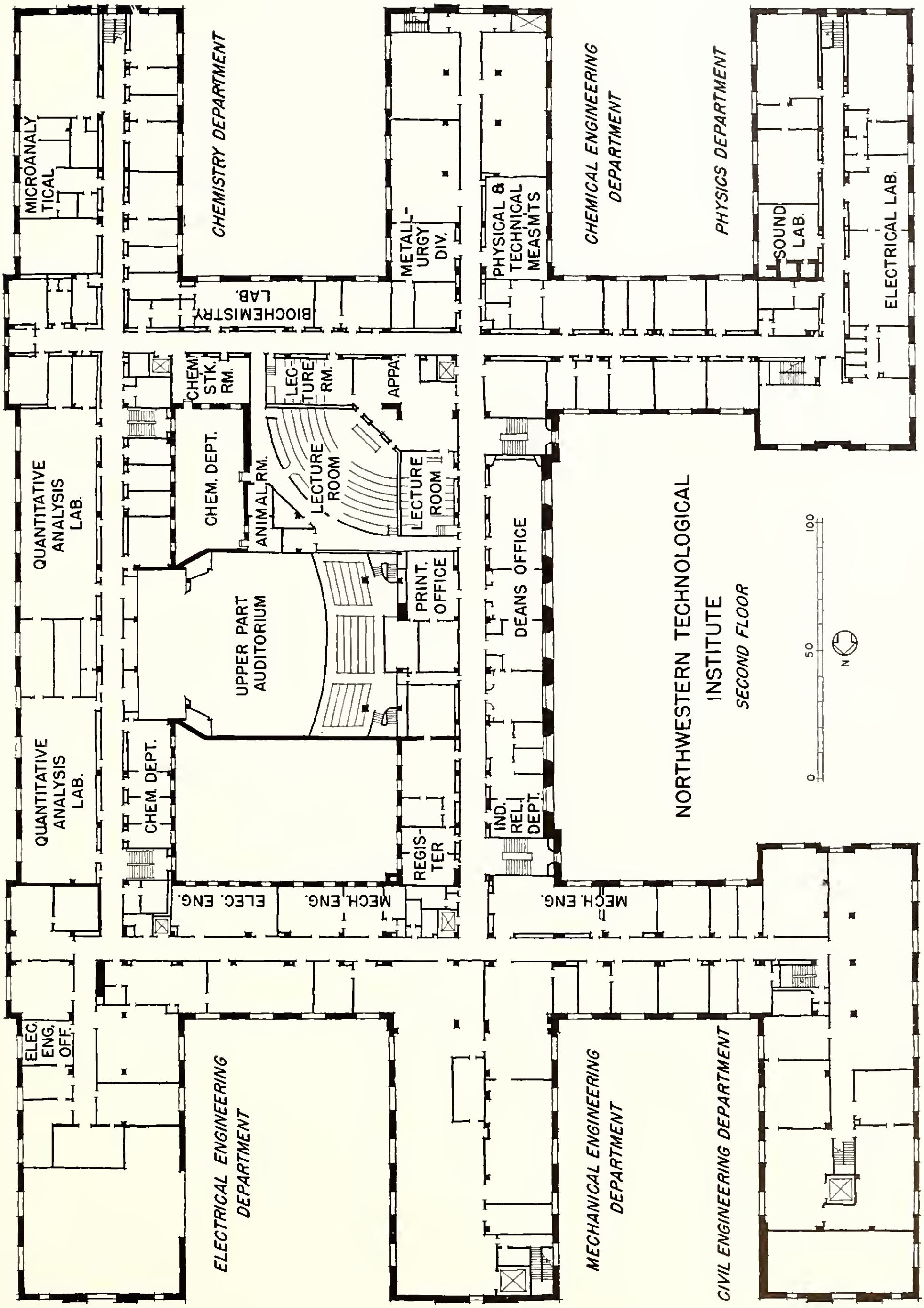

NORTHWESTERN TECHNOLOGICAL INSTITUTE
SECOND FLOOR
0
50
100
N
CHEMISTRY DEPARTMENT
CHEMICAL ENGINEERING DEPARTMENT
PHYSICS DEPARTMENT
ELECTRICAL ENGINEERING DEPARTMENT
MECHANICAL ENGINEERING DEPARTMENT
CIVIL ENGINEERING DEPARTMENT
MICROANALYTICAL
BIOCHEMISTRY LAB.
METALLURGY DIV.
PHYSICAL & TECHNICAL MEASMTS
SOUND LAB.
ELECTRICAL LAB.
QUANTITATIVE ANALYSIS LAB.
CHEM. STK. RM.
LECTURE RM.
APPA.
CHEM. DEPT.
ANIMAL RM.
LECTURE ROOM
LECTURE ROOM
UPPER PART AUDITORIUM
PRINT. OFFICE
DEANS OFFICE
QUANTITATIVE ANALYSIS LAB.
CHEM. DEPT.
IND. REL. DEPT.
REGISTER
ELEC. ENG.
MECH. ENG.
MECH. ENG.
ELEC. ENG. OFF.

Figure IV.9c.

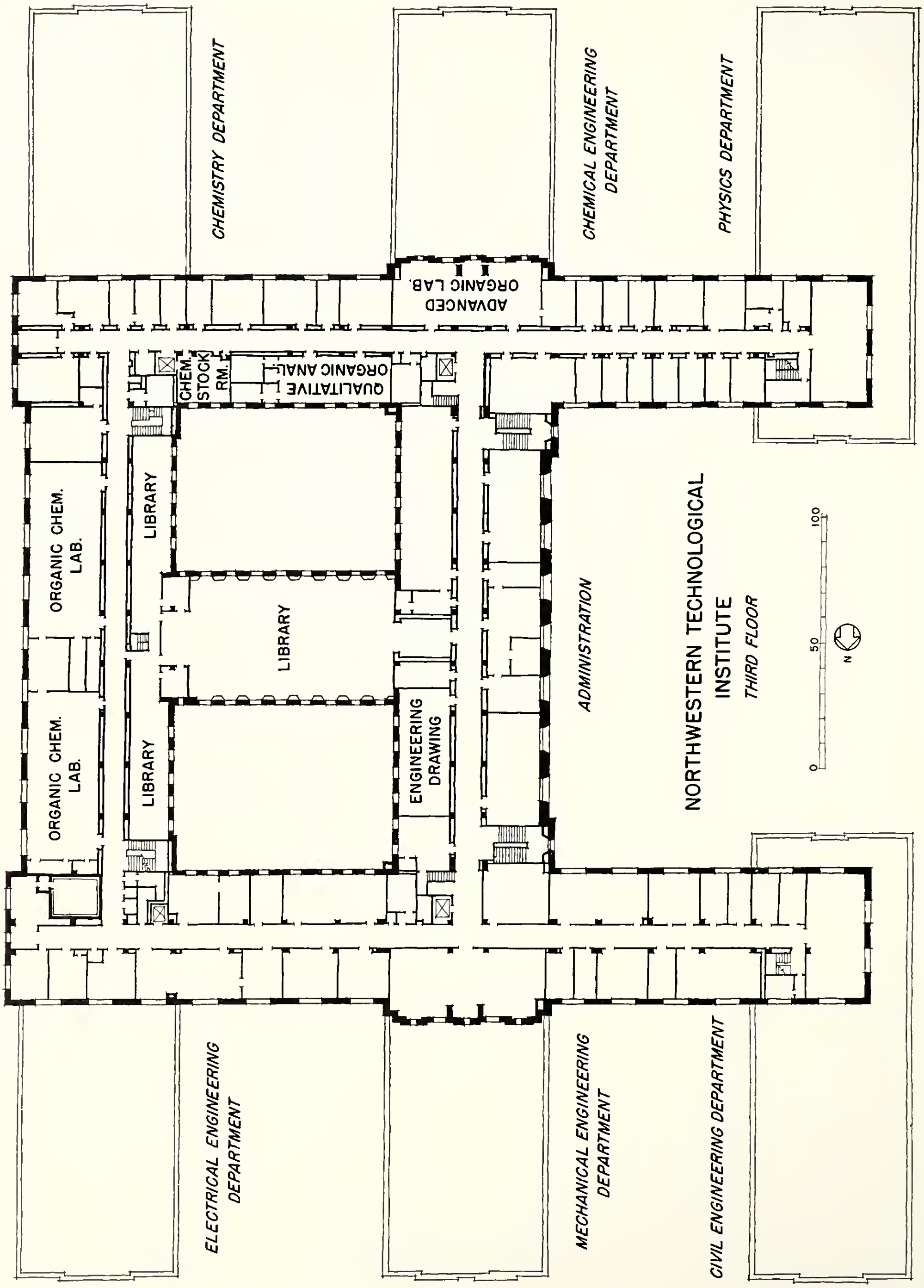

CHEMISTRY DEPARTMENT
CHEMICAL ENGINEERING DEPARTMENT
PHYSICS DEPARTMENT
ADVANCED ORGANIC LAB.
CHEM. STOCK RM.
QUALITATIVE ORGANIC ANAL.
ORGANIC CHEM. LAB.
LIBRARY
LIBRARY
ORGANIC CHEM. LAB.
LIBRARY
ENGINEERING DRAWING
ADMINISTRATION
NORTHWESTERN TECHNOLOGICAL INSTITUTE
THIRD FLOOR
0
50
100
N
ELECTRICAL ENGINEERING DEPARTMENT
MECHANICAL ENGINEERING DEPARTMENT
CIVIL ENGINEERING DEPARTMENT

Figure IV.9d.

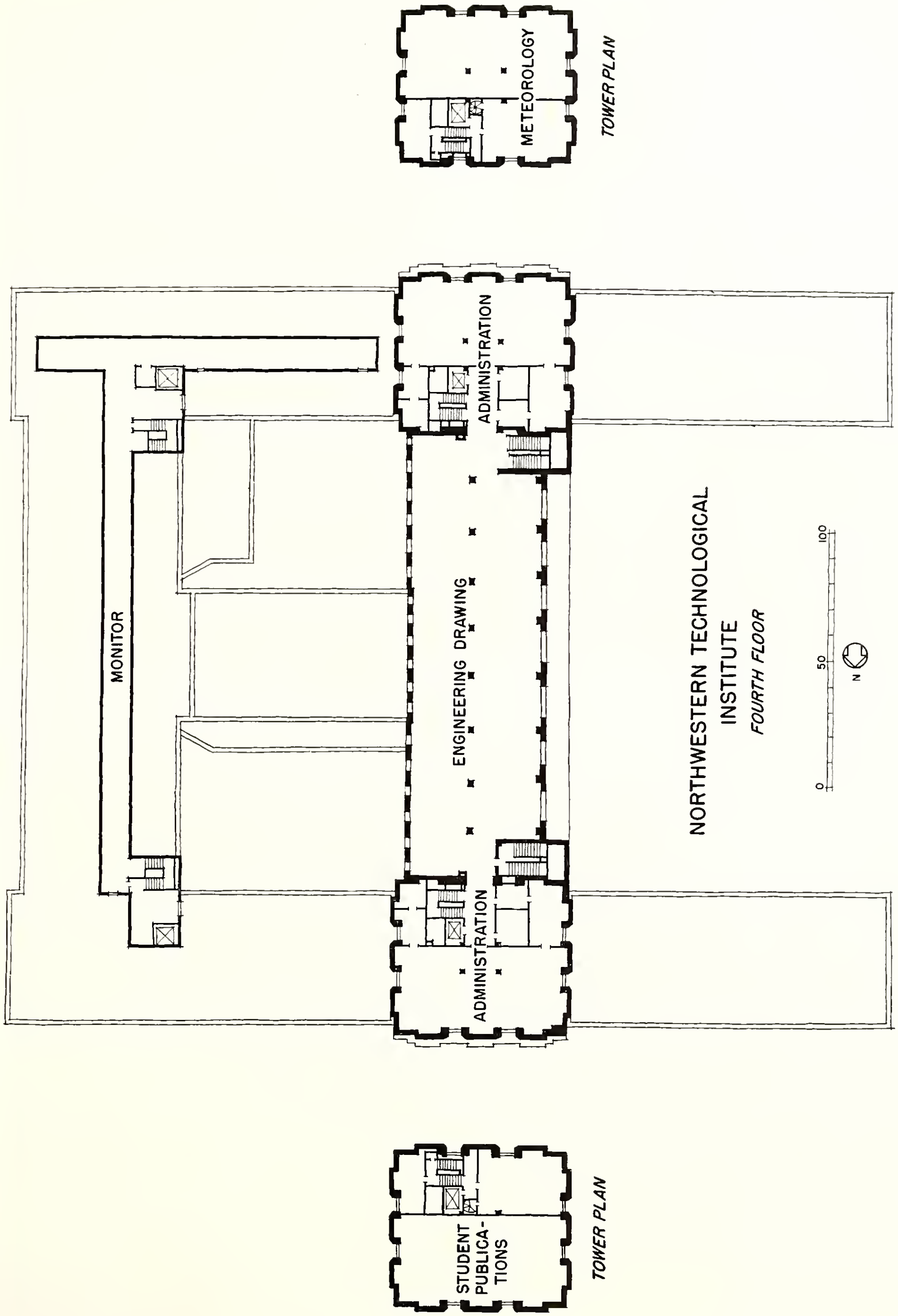

NORTHWESTERN TECHNOLOGICAL
INSTITUTE
FOURTH FLOOR
0
50
100
N
MONITOR
ENGINEERING DRAWING
ADMINISTRATION
ADMINISTRATION
METEOROLOGY
TOWER PLAN
STUDENT
PUBLICA-
TIONS
TOWER PLAN

Figure IV.9e.

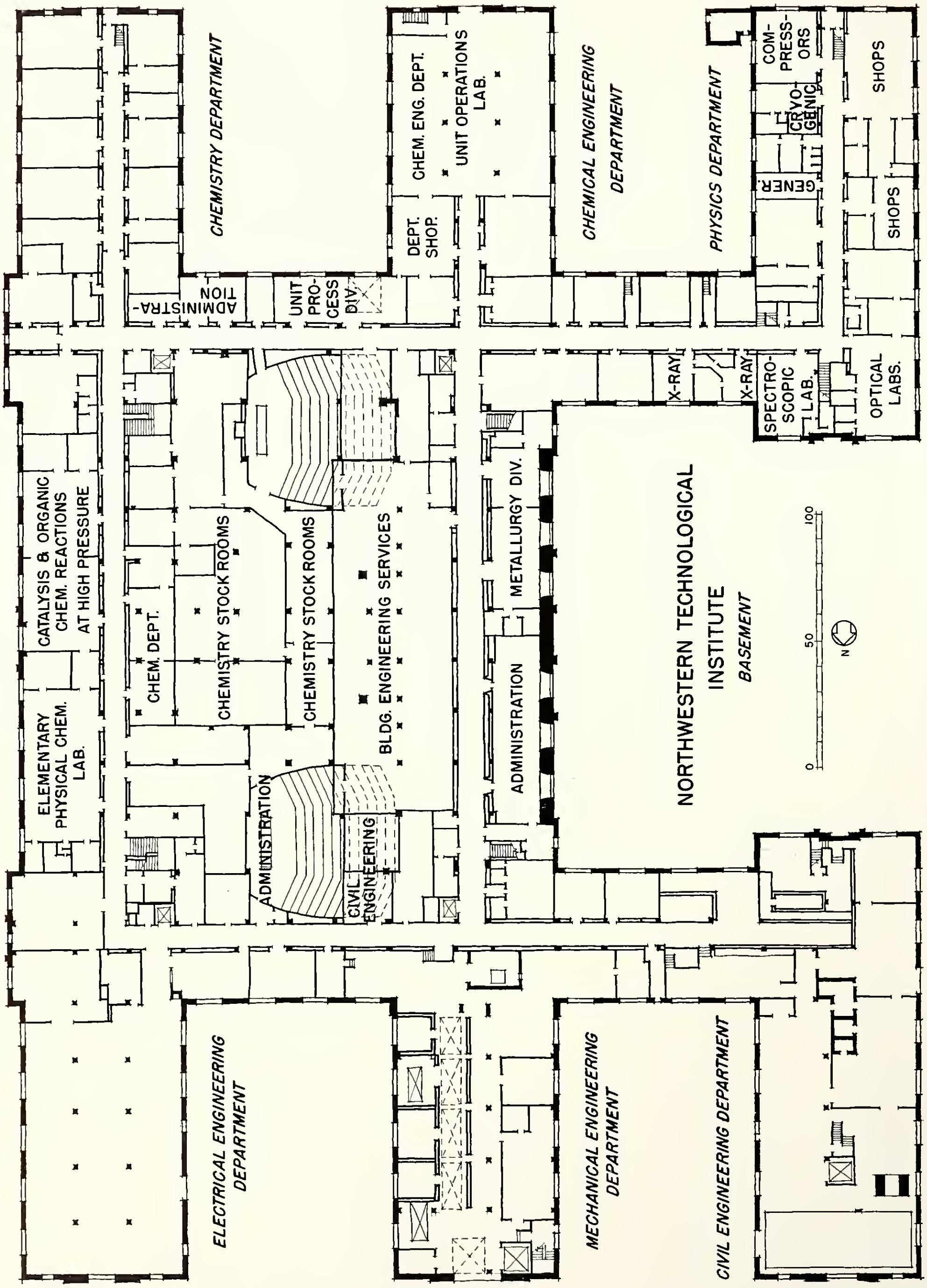

CHEMISTRY DEPARTMENT
CHEM. ENG. DEPT. UNIT OPERATIONS LAB.
DEPT. SHOP.
CHEMICAL ENGINEERING DEPARTMENT
PHYSICS DEPARTMENT
COM-PRESS-ORS
CRYO-GENIC
GENER.
SHOPS
SHOPS
ADMINISTRA-TION
UNIT PRO-CESS DIV.
X-RAY
X-RAY
SPECTRO-SCOPIC LAB.
OPTICAL LABS.
CATALYSIS & ORGANIC CHEM. REACTIONS AT HIGH PRESSURE
CHEM. DEPT.
CHEMISTRY STOCK ROOMS
CHEMISTRY STOCK ROOMS
BLDG. ENGINEERING SERVICES
METALLURGY DIV.
ADMINISTRATION
NORTHWESTERN TECHNOLOGICAL INSTITUTE
BASEMENT
0
50
100
N
ELEMENTARY PHYSICAL CHEM. LAB.
ADMINISTRATION
CIVIL ENGINEERING
ELECTRICAL ENGINEERING DEPARTMENT
MECHANICAL ENGINEERING DEPARTMENT
CIVIL ENGINEERING DEPARTMENT

Figure IV.9f.

the registrar, and the printing service offices (figure IV.9c). These administrative offices can be seen to be centrally disposed with respect to the engineering departmental offices: chemical, civil, electrical and mechanical (figure IV.9c). This is not only a convenience but a highly welcome feature. Centrally located, also, are the main auditorium seating 800, two large lecture rooms of 300 capacity each (see figure IV.11) and various other lecture rooms of about 100 seating capacity. Lecture rooms, together with twenty-five classrooms conveniently located throughout the building, are capable of accommodating 1,700 students simultaneously.

Building engineering services are mainly in the basement. Central power panels and circuit breakers, air conditioners, refrigeration machines, heat converters,

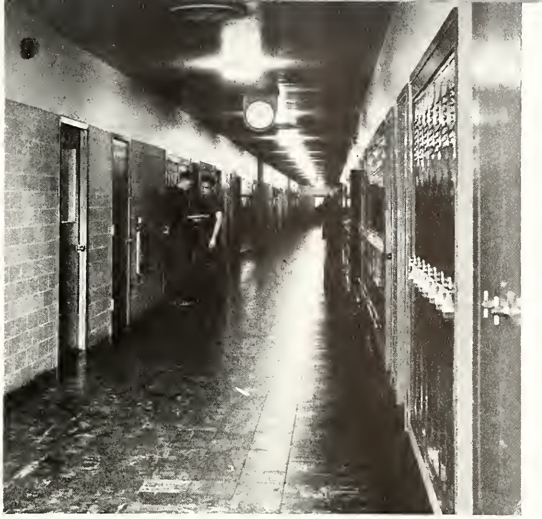
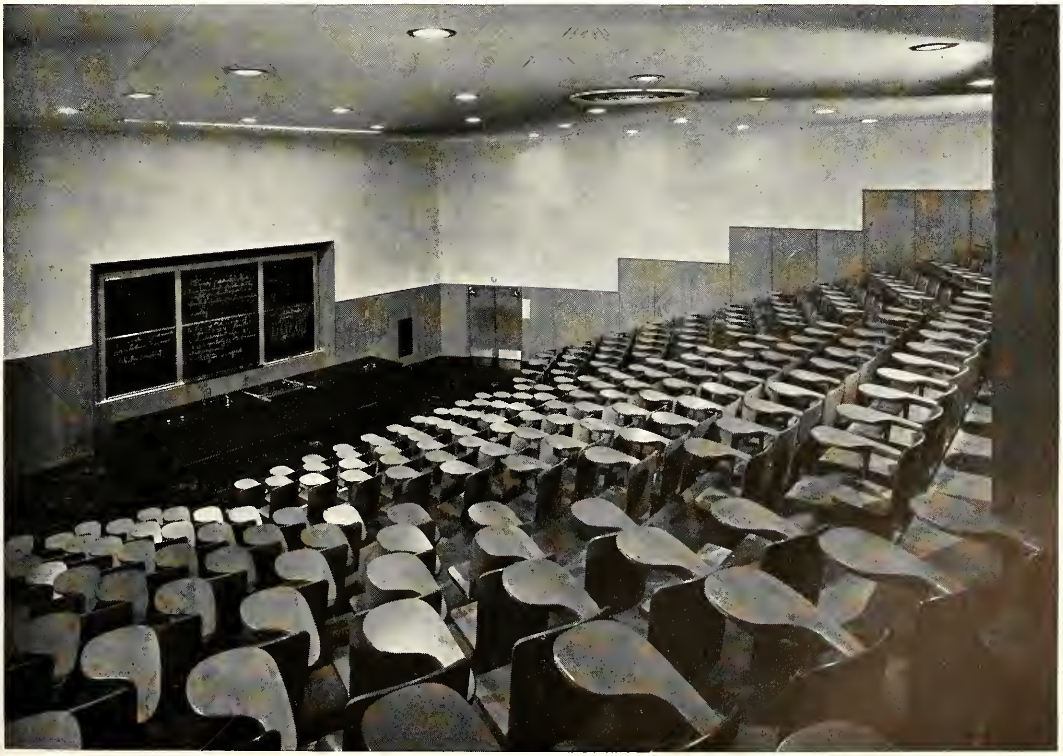


Figure IV.10 Building corridor; note inset lockers and clock.

Figure IV.11 Large lecture room (Hedrich-Blessing Studio, Chicago).



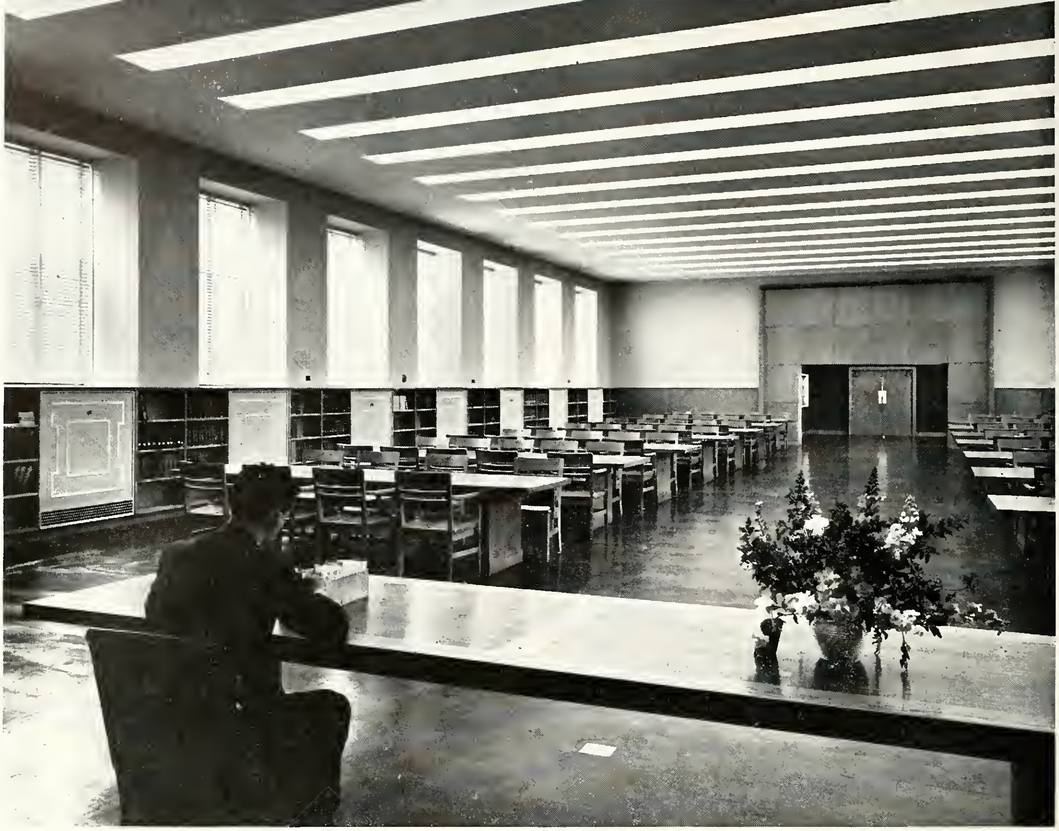
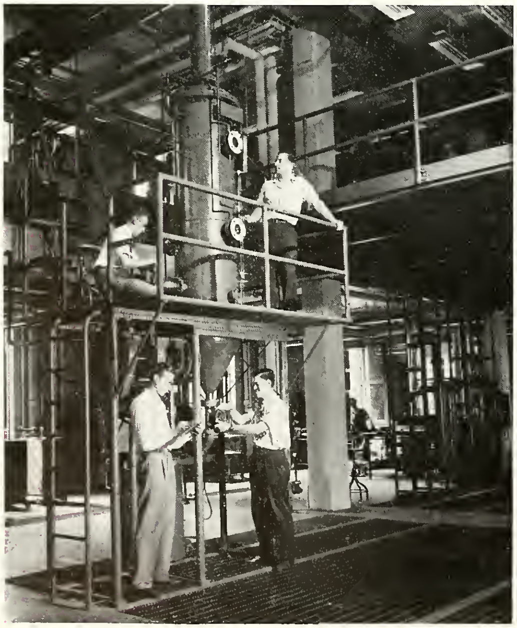


Figure IV.12 General reading room of library (Hedrich-Blessing Studio, Chicago).

Figure IV.13 Unit operations laboratory in chemical engineering; note multiple grating levels.



etc., are in the 900 series rooms indicated in figure IV.9f. The heat converters condense intermediate-pressure steam from the university power house against recirculated water from the room convectors. Hot water is thus used to heat the building. A "Duostat" system of control is used for the comfort heating system: as the outside temperature falls below 70° F, the water in the convectors is increased in temperature. In addition to the regular academic features, considerable attention has been given to staff and student comfort. Individual lockers (figure IV.10) are provided, and modern washrooms, shower baths, etc., are conveniently located. A student lounge and adjacent fully equipped kitchen are also available.

The library (figure IV.9d and figure IV.12) contains the collections of chemistry, physics, and engineering. General references are shelved in the reading room while the main collections and bound periodicals are in the stacks which have space for 75,000 volumes. The entire library is on the "open" principle and all students have full access to the stacks. There are forty individual study carrells in the stack sections for the use of faculty and graduate students.

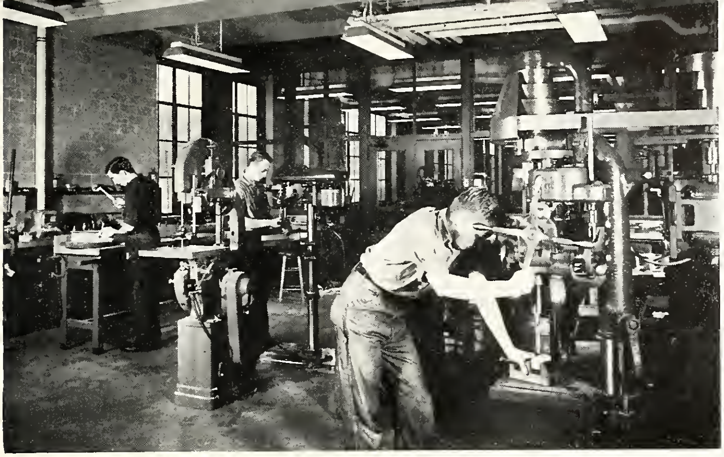


Figure IV.14 Chemical engineering shop (Hedrich-Blessing Studio, Chicago).

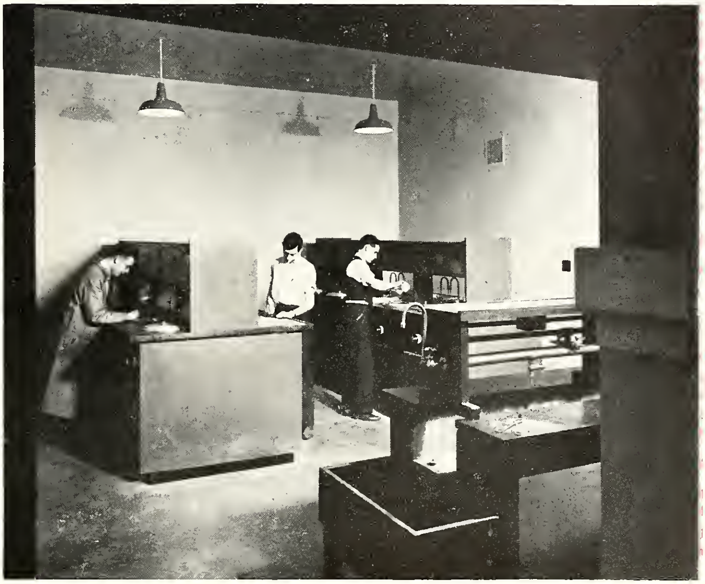


Figure IV.15 Metallurgy laboratory for specimen preparation (Hedrich-Blessing Studio, Chicago).

Chemical Engineering

The Chemical Engineering Department (including the Metallurgy Division) is housed in the south central wing of the building. About one quarter of the total area of this department is devoted to the unit operations laboratory (figure IV.9f). Figure IV.13 shows the use of multiple steel grating levels in this laboratory which allow adequate work platforms at the necessary height stations on the equipment. The use of a grating floor should also be noted. Adequate drainage and safe footing are assured during "sloppy" operations. A proper balance, however, is maintained in terms of concrete floor for movement of equipment.

In this laboratory, equipment associated with the physical processing of materials important to chemical technology is used to demonstrate operational principles. All items are operated by students in laboratories and on research programs, and all equipment is of such size that results are of significance for industrial design or operation practice.

The Physical Measurements Laboratory and Technical Measurements Laboratory (figure IV.9c) are well equipped for precise studies and instruction in typical measurements associated with chemical engineering. Many instruments have been calibrated by the Bureau of Standards and practically all have been corrected in terms of these secondary standards. Routine tests such as ASTM distillations, Reid vapor pressures, surface tension, gas densities, etc., may be performed.

The Unit Process Laboratory (figure IV.9f) has equipment for pilot-scale manufacture of chemical sub-

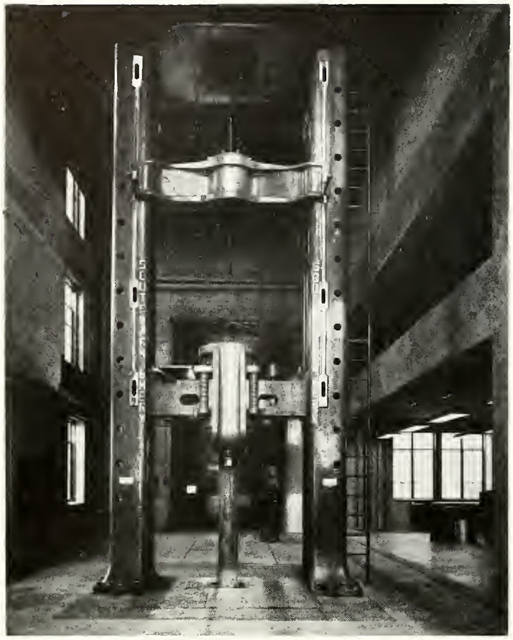


Figure IV.16 1,000,000-pound testing machine in materials laboratory; note crane-way and balconies (Hedrich-Blessing Studio, Chicago).

stances. This equipment is made of stainless steel or glass-lined steel. A section is also devoted to high-pressure investigations.

The department shop (figure IV.9f and figure IV.14) is similar to those possessed by each of the six departments in the building. It is conveniently located with respect to the Unit Operations Laboratory and unit processes section (figure IV.9f). The use of metal partition to develop a space is again to be noted here.

The metallurgy division (figure IV.9f and figure IV.9c) is equipped to offer demonstrations and practice in metallography and other phases of physical metallurgy. A Bausch and Lomb horizontal inverted research-type photometallograph is available for precise work. Supplementing the work of this division are several microscopes, polishing and grinding equipment (see figure IV.15), specimen presses, testing machines, and photography darkrooms with complete equipment (figure IV.9f).

Within the department are several rooms, which are in effect open space. Services have been installed and it is possible to build research equipment or project devices. At the conclusion of the work, the apparatus may be dismantled or transferred to a more permanent situation thus availing the space for further use.

The department lacks research office combination

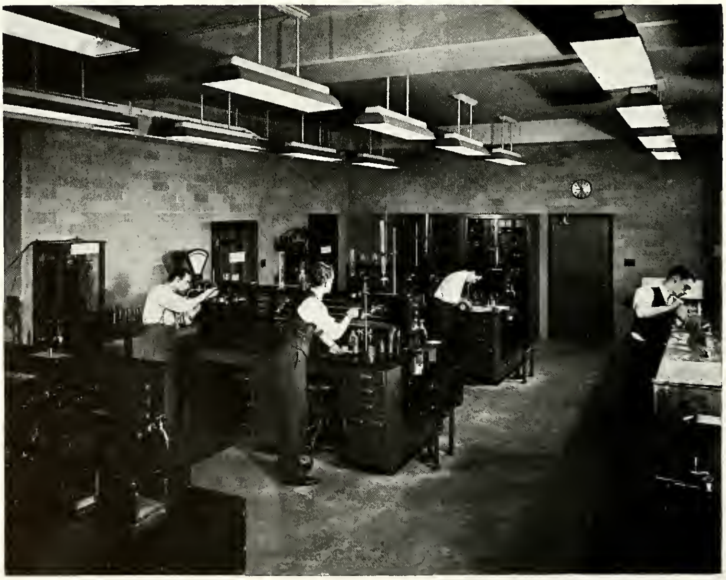


Figure IV.17 Cement and bituminous materials laboratory; note kneehole desks (Hedrich-Blessing Studio, Chicago).

suites such as chemistry possesses and central storage space. Designers of engineering buildings should carefully consider these two items.

Civil Engineering

The Department of Civil Engineering, occupying the northwest wing of the Institute, has extensive laboratory and research facilities for the study of the mechanical behavior of structural materials and members, of concrete and highway materials, of soils for engineering applications, and of water for hydraulic and sanitary engineering applications.

Electrical Engineering

The Department of Electrical Engineering occupies the northeast wing and a portion of the adjoining east-west section. Laboratories and facilities are available for research and instruction in electrical machinery, high voltage, electric controls and servomechanisms, electrical measurements, electronics, communications, and acoustics. Electrical power in wide ranges of frequency and voltage is available in every laboratory.

Mechanical Engineering

The Department of Mechanical Engineering occupies the north center wing. On the ground and first floors are those laboratories associated with heat, power, and thermodynamics. The second floor is devoted to shop work and the materials of manufacture, and the third floor and main body of the building house the machine and tool-design rooms, precision inspection laboratory, and other classrooms.

Chemistry

The Chemistry Department is housed in the southeast wing and east side up to the northeast wing.

Constant-temperature rooms and storeroom facilities are in the sub-basement, physical chemistry laboratories and research rooms as well as many staff offices and the general storeroom are on the ground floor. Departmental offices, other staff offices, and the laboratories in general chemistry are on the first floor. Large laboratories for work in analysis and biochemistry are on the second floor together with the microanalytical laboratory and many research laboratories in organic chemistry. The third floor is devoted entirely to organic chemistry.

The various laboratories of the building are equipped with wood desks topped with "Alberene" stone. At the doorway of each laboratory is an emergency shower for use in case of fire or severe acid burns. Fire extinguishers are in the halls and in the student laboratories. Each laboratory is equipped with aluminum wall channels, placed vertically at three-foot intervals, and in the more open rooms of many of the research labora-

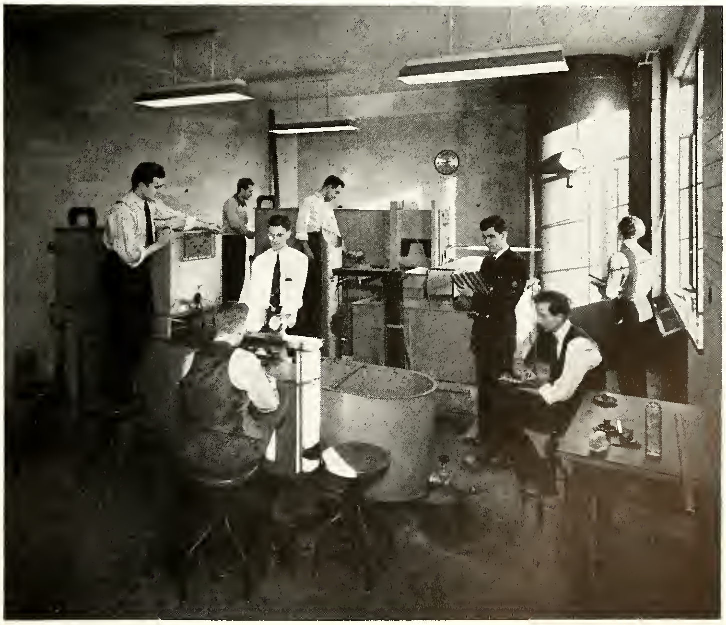


Figure IV.18 Hydraulics laboratory. Typical of many "open space" rooms which allow temporary set-ups (Chicago Architectural Photographing Company).

tories ceiling slots are also an integral part of the building, such facilities making possible the suspension of apparatus or services from the walls or ceiling.

Facilities for 608 students in elementary chemistry are divided into three laboratories (figure IV.9b and figure IV.22) so that the students may be conveniently sectioned according to interest and experience. This arrangement brings the student into constant contact with one instructor with whom he becomes well acquainted. A new simplified type of chainomatic balance was developed for use in these laboratories which permits the student to do exact quantitative work in the minimum time. Individual down-draft hoods and semimicro equipment including individual sets of reagents enable students to spend time doing experiments and learning chemistry rather than wandering about the laboratory.

Two large laboratories (figure IV.9d) accommodating 225 organic chemistry students are on the third floor. Each student has 5 linear feet of table space and a sink which he shares with one other student both for convenience and safety. The inside walls of the rooms are generously provided with efficient hoods.

These laboratories have connecting balance rooms, coat rooms and service room. Student tables are equipped with air, steam, water, electricity, and gas. One feature of the tables, common to all student laboratories, is a long drawer capable of holding long condensers and tubing. The design of the shelving also is such that both tall and short equipment may be stored readily in the tables.

An advanced organic laboratory (figure IV.9d), capable of accommodating 18 students in two sections, is also on the third floor. It is designed for preparations to be worked either on the tabletop or on the floor adjacent to the wall which is well equipped with services. This laboratory also is supplied with a connecting balance room.

There is also on this floor a room particularly designed for qualitative organic analysis. This room (figure IV.9d) is capable of handling 32 persons in two sections. Leading from this laboratory are a coat room, a balance room, and a service room for the course.

Two large laboratories (figure IV.9c and figure IV.19) for instruction in quantitative analysis are on the second floor. Each student is generously provided with table space. Large hoods with controlled top and bottom draft, and specially designed tiers of steam baths with drafts across the tops of the baths are provided on the inside walls of these rooms. Separate balance rooms with chainomatic balances are provided for all undergraduate work. The balances are placed on small shelves below which is a long, broad table to provide students with ample desk space on which to lay their

Figure IV.19 Quantitative analysis laboratory; note trough, spot, and end, sinks and steam baths at right (Chicago Architectural Photography Company).

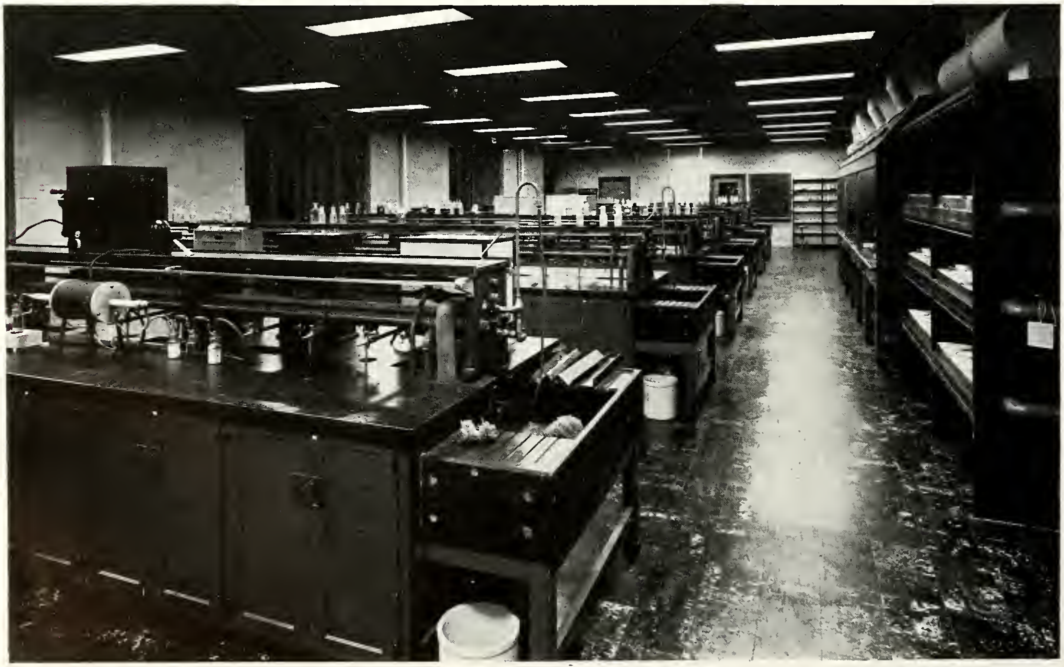
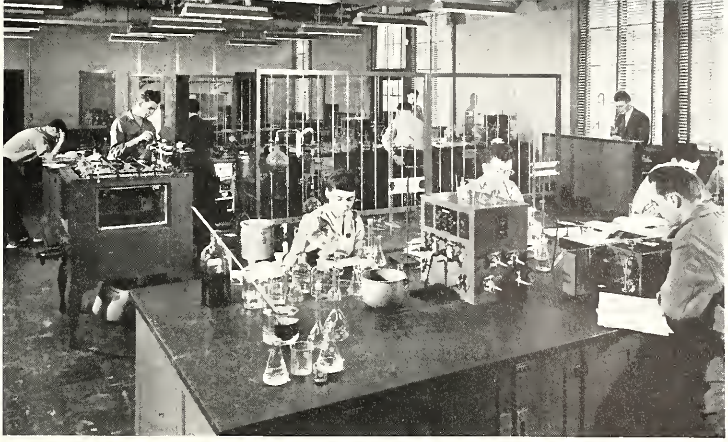
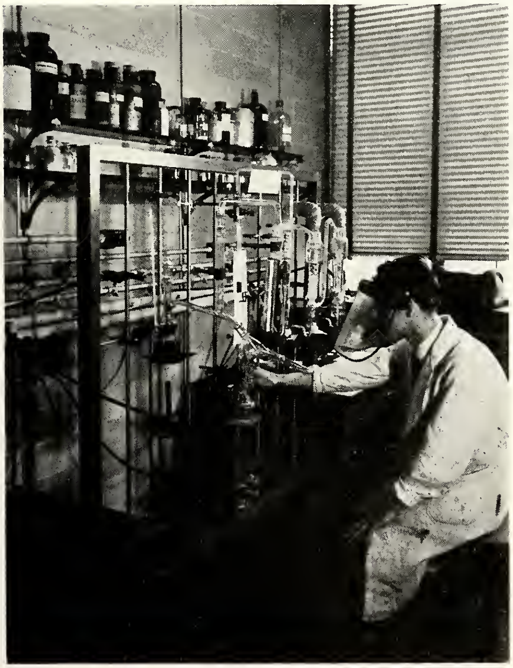


Figure IV.20 Physical chemistry laboratory (Hedrich-Blessing Studio, Chicago).



notebooks and desiccators while weighing. In the combined elementary physical chemistry and quantitative analysis laboratory is a special room for the storage of tall apparatus which may have been assembled by each individual student; there is also a room which the students may use in turn, containing single pieces of such expensive apparatus as du Nouy tensiometers, glass-electrode pH electrometers, and Wheatstone bridges. A coat room across the corridor is available for student use.

Figure IV.21 Research laboratory; note wall strip insert and Krans-Franklin grill.



There is one large laboratory (figure IV.9f and figure IV.20) in the basement for elementary physical chemistry, which will accommodate two sections of thirty students each, and a small laboratory for more advanced work. The advanced laboratory has the same equipment as the research laboratories of physical chemistry. In the elementary laboratory the student, besides having the usual table space, has direct access to a fixed frame extending from a table 2 feet high to a height of 7 feet above the floor. The frames are equipped with all the customary services and make for easy mounting of large apparatus. Besides the usual services provided in all the chemistry laboratories, oxygen is piped to each table. This table is used for glassblowing and as a standard in studying physical properties of gases. Water thermostat baths are provided for the study of properties at various constant temperatures. Adjoining the laboratory are balance rooms with analytical, heavy duty, and specific gravity balances. A darkroom permits photochemical studies with visible light, and a special wiring system enables the distribution of electrical current of different voltages or frequencies to each student table.

The facilities in biochemistry are sufficient for all types of biochemical work. Most of the procedures carried out in the undergraduate laboratory are conducted on a quantitative basis. A large titration rack has been constructed in the middle of the laboratory (figure IV.9c) and is easily accessible for all students. All standard solutions are siphoned directly into the burettes so that the students can conduct a maximum number of experiments in a minimum amount of time.

There is a completely air-conditioned animal room (figure IV.9c). The specially-designed cages in the animal room are quite flexible for keeping many types of animals with a minimum amount of attention.

The various rooms for investigations in organic chemistry on the second and third floors are designed to accommodate sixty to seventy research workers. All of these laboratories are built with slotted walls to assist in the construction, either of shelving on the wall, or of chemical equipment (figure IV.21). Each room is equipped with water, distilled water, gas, air, steam, AC and DC current. In addition to his laboratory table, each research worker is provided with a study desk. Portable tables are accessible for any laboratory. Each laboratory is equipped with one or more hoods, and beneath most of the hoods is a steam-heated cabinet for drying apparatus.

For each ten to twelve organic research workers there is provided an accessible room for apparatus used by this group. These rooms are a convenience in storing or constructing apparatus which would be injured by laboratory fumes or which would obstruct work on a laboratory table. Such items as analytical balances, drying ovens, sodium presses, shakers, etc., are placed in these rooms.

Five research laboratories in the basement wing, in addition to four laboratories leading from professors' offices, are designed for research work in physical chemistry.

The entire ground floor of the southeast wing is so arranged that it can be separated from the rest of the building, thus allowing the physical chemistry research laboratories to be air conditioned in summer time. In this way electrical difficulties arising from high relative humidity can be avoided. Student writing desks and chairs in each laboratory, blackboards in laboratories and offices, hoods, adjustable stools, numerous stainless steel apparatus frames, emergency showers, balance shelves with underlying larger shelf are also included in these laboratories.

Experimental work in catalysis and organic chemical reactions at high pressure is provided for by a suite of rooms (figure IV.9f) on the ground floor particularly designed for this type of experimentation. There is a separate bomb room and a room for gas analysis in addition to the usual type of research equipment.

A laboratory (figure IV.9c) maintained at constant temperature and constant humidity for microanalytical work is located on the second floor. It consists of one large room partitioned off with two rooms leading from it, one a dark room and one a balance room. This room is designed primarily for research work and for instruction in microanalytical techniques. It is well equipped with microbalances and microanalytical equipment.

Provision was made in the construction of the building for construction of tall equipment such as distillation or extraction columns. A shaft 75 feet high extends from the sub-basement to the top of the building, and at each floor level the walls of this 10-foot square shaft are generously provided with the usual laboratory services so that any anticipated experiments could be carried out therein. Removable floors are in place at each floor level.

The chemistry stock room is in the basement and extends beneath the auditorium (figure IV.9f). In addition, there are branch stock rooms on the second and third floors connected to the main stock room both by the elevator and by a dumb-waiter system. Each of the large student laboratories also has its stock room which is designed to serve the course in the adjacent laboratory. The main stock room is equipped with an efficient glassware laundry, a metal enamelling room, and various storage rooms. Separate rooms, equipped with an automatic carbon dioxide system for fire protection for dangerous chemicals and for storage of solvents, are in the sub-basement.

Physics

The Physics Department is in the southwest wing of the building. Student laboratories, lecture and recitation rooms are on the main and second floors. Elementary laboratories, because of the large number of students in such courses, are on the main floor. Offices are in a group on the main floor in order to be easily accessible to the student. Special installations, such as compressors for liquefaction of air and hydrogen, x-ray equipment, generator rooms, shops, and special research rooms (figure IV.9f), are located on the ground floor. In the sub-basement are research rooms and installations requiring freedom from vibrations, such as soundproof rooms and spectroscopic grating mountings and equipment. Included in this group, with their floors in the sub-basement, are two 2-story rooms for possible high potential research. Third-floor rooms are set aside for research.

Lecture rooms (figure IV.9c) are located on the second floor in the central section of the building. The large lecture room, with a seating capacity of 200, is fan-shaped with an angle of 90°. The lecture table, 18 feet long, is located near the apex of the fan. Seats form quarter circles on graduated steps in coliseum style with riser heights varying from 6 to 10 inches to provide effective observation of the lecture demonstrations. Without the graduated steps the ceiling height would be 12 feet. A recess raises this ceiling height above the lecture table to 14 feet, making possible effective indirect lighting and providing a space for supports moving on rails from which to suspend apparatus. The acoustically treated rear wall and ceiling affords excellent auditory conditions. The lecture table is provided with gas, compressed air, steam, hot and cold water, adequate electric service, and controls for automatic projection lantern, sound projection equipment, motor-driven screen, projection voltmeter and ammeter. The voltmeter and ammeter are placed in two projection lanterns in a fan-ventilated box in the front row of seats; their scales, when projected on a screen behind sliding glass blackboards back of the lecture table, are 5 feet long. There are no windows in the room. Illumination is controlled by means of a dimmer. The room is air conditioned.

All three lecture rooms adjoin a lecture apparatus room (figure IV.9c) equipped with cases of 3,400 cubic feet storage capacity. The equipment for this room consists of electric supply, gas, air, hot and cold water, sink, work tables and transport tables.

The five elementary laboratories (figure IV.9b), on the first floor are practically identical in size and equipment. Each room is 21'0" by 40'0" and is arranged to accommodate a maximum of 20 students. The attempt is made to limit the size of the laboratory sections to 16 students for each instructor. These laboratories are supplied with five "islands" equally spaced in a line through the middle of the room. They are provided with sinks, hot and cold water, air, gas, and an electric panel with jacks connected to circuits from a distribution board in the room. The panel has AC and DC power supply and transfer circuits to the main switchboard. A folding top over the sink is flush with tables 3'0" by 6'0" on each side of it. At convenient stations on the walls are small electric panels with jacks connecting to circuits leading to the distribution board.

The electrical laboratories on the second floor constitute a suite with an associated apparatus room. The three rooms (figure IV.9c) are planned for work in electric measurements, advanced electric measurement and electronics, respectively. The suite has an adequate electric power distribution board which, in addition to the 120- to 208-volt supply, has 4-, 8-, 12- and 24-volt and regulated 120-volt AC supplies. From the jacks on the board transfer circuits lead to the main supply board on the second floor and to the small panels at many locations on the walls of the laboratory.

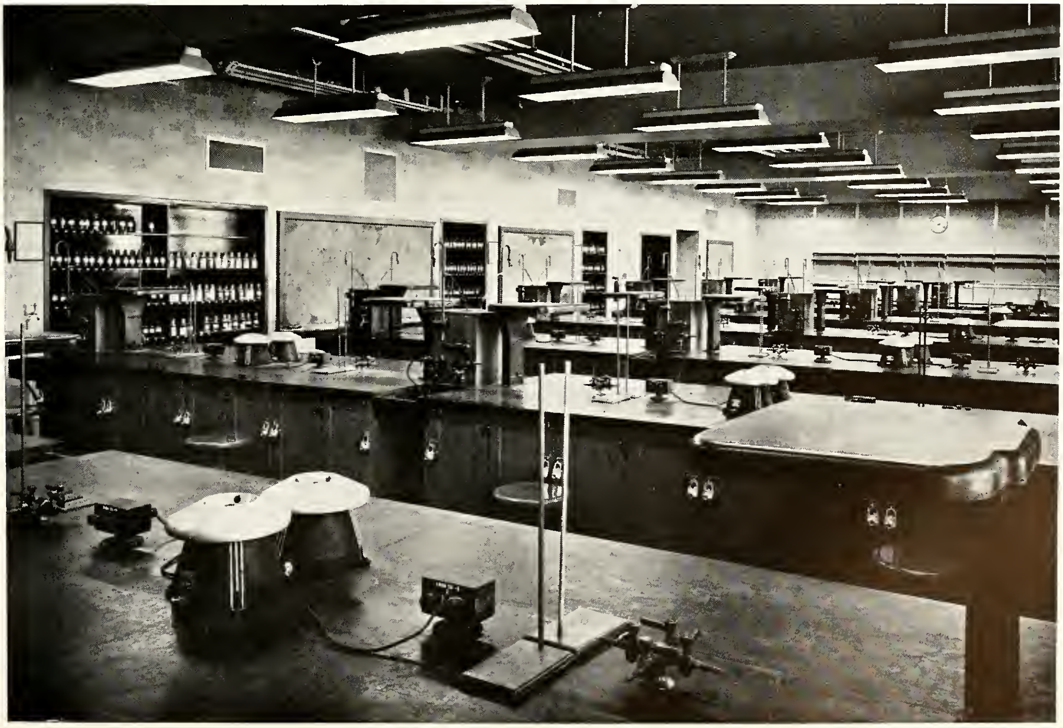
The student spectroscopic and optical laboratories are located in the basement (figure IV.9f). Between these two laboratories are a darkroom and an apparatus room provided with cases, work benches, and so forth, for minor repairs. Also adjoining the optical laboratory are four cubicles for experiments requiring at times no illumination. Each cubicle has a port 3 feet from the floor for systems in which it is desirable to isolate either the source or observer.

The room (figure IV.9f) housing the compressors for air and hydrogen liquefaction has a floor—independent of the building—of reinforced concrete mounted on piers extending to the same depth as the building footings. A floor drain, 12" by 6", covered with a steel grating extends about three sides of the room. All equipment in the room is explosion-proof.

The air liquefier has a capacity of 25 liters/hour which is attained by precooling the air to —28° C with a 3" by 3", 2-ton ammonia machine. The process for liquefying air is as follows: atmospheric air is washed by a caustic spray, compressed, water cooled, dried by caustic and silica gel, precooled and expanded from a Hampson-type exchanger.

The process for hydrogen is as follows: tank hydrogen is compressed, water cooled, dried, precooled and purified in a charcoal trap at liquid-air temperature; it is further cooled by liquid air boiling at reduced pres-

Figure IV.22 General chemistry laboratory; note desk top hoods, inset shelving, and experimental electrical panels (Hedrich-Blessing Studio, Chicago).



sure and is then liquefied by means of expansion in an exchanger coil in a Dewar container. The capacity of this liquefier is 8 to 10 liters/hour. The vacuum for the hydrogen exchanger is produced by a molecular pump backed by a Cenco "Hypervac" pump, and the pressure over the boiling air is reduced by a Beach-Russ rotary pump with a capacity of 75 cubic feet/minute. The tank hydrogen is stored in a gasometer in a small building outside of the room.

These installations serve both as equipment for research and as sources of supply of refrigerants for other departments in the building.

Cryogenic research space is provided. Adjoining an adequate research room (figure IV.9f) is a cold room (13°C) the temperature of which may be reduced to —40°C. It is insulated with 8 inches of cork blocks overlapping in two layers and sealed in Hydrolene. The walls are finished with an asphalt base and successive coats of cement plaster, asphalt emulsion and aluminum paint. The floor is of concrete 3 inches thick set on 8 inches of cork. The entry to the room is through a small anteroom lined with cork 4 inches thick. The room is equipped with cooling coils for drying the air before it enters the main room. The door to the entry room is a standard refrigerator door and the door to the main room is a "Superseal" refrigerator door.

This type of construction allows the main room to be operated for a period of probably eight months without defrosting. The entry room is at a temperature between 0° and —5° C. Thermostatic control will hold the temperature of the main room between —33° and —36° C with the compressors operating less than 10% of the time. In cooling, a temperature drop from +20° to —25° C is effected in four hours; the drop to —40° C requires an additional eight hours of operation.

Observations in the cold room may be made through a window consisting of four thicknesses of plate glass, spaced ½ inch apart. The spaces between the glass are partially filled with calcium chloride to prevent frosting. The window is closed on the outside by a standard refrigerator door.

Sound laboratories for student use are located on the second floor. They consist of one moderate sized room, (figure IV.9c), with three small soundproof rooms at one end. The main room is supplied with electric panels, air, gas, hot and cold water. The small soundproof rooms are lined with 8 inches of rock wool throughout, and are equipped with Riverbank 42-decibel doors. The walls between the rooms have openings 1 meter square for sound transmission measurements and similar work. These openings may be closed by double soundproof doors.

Larger soundproof rooms in the sub-basement required considerable thought. They form a suite of three, consisting of a control room, a room 12'0" by 9'0" by 8'0", and one 17'0" by 13'0" by 10'0". The detail of the larger of these rooms is as follows. It consists of a walled enclosure housing the room. This inner room, which is mounted on rubber, has a mass of 100,000 pounds; it has a reinforced concrete floor and ceiling and walls of a double layer of sound-absorbing tile. The tile is laid with no coincident joints. The whole is as nearly monolithic as this type of construction would allow. After some experimentation it was decided to mount the room on rubber loaded to give the whole a period of about two seconds. Experiments had shown conclusively that rubber properly loaded considerably excelled damped springs. There is no assurance, however, that the rubber will not deteriorate. In such an event sealed concrete plugs in the floor may be lifted, the load removed from the rubber by hydraulic jacks and a new material used. The inner and outer sides of the walls of the room are covered with a one inch layer of "Sprayoflake", a material consisting of flaked paper and a mastic. For further sound absorption, and also to prevent internal reflection, the ceiling and walls of the room are covered with 16 layers of spaced muslin and flannel. The entrance to the room from the control room is closed by specially designed, double soundproof doors. No electric circuits enter the room and it has no ventilation, owing to the problem of sound insulation introduced when such features are present.

The medium-sized room is constructed in a similar manner except for the wall covering, which is 4 inches of glass wool. The floors in both this and the larger

TABLE IV. 3

Personnel Occupancy

Impermanent:	
Undergraduate engineering students	900
Graduate engineering students	130
Graduate physics students	50
Graduate chemistry students	150
total	1230
Permanent (space assigned):	
Engineering faculty	65
Engineering assistants	40
Engineering staff	55
Physics faculty	15
Physics assistants and staff	20
Chemistry faculty	30
Chemistry assistants	70
Chemistry staff	10
Building services staff	30
Project workers	85
total	420

The building is used also for classes in the College of Liberal Arts and Sciences. Altogether, these classes may amount to an additional 400 students. The daily population figure for the Institute is thus in the order of 2000 individuals.

TABLE IV. 4

Northwestern Technological Institute Color Code for Mechanical and Electrical Services

The base color for all services shall be the color in the room or if in unpainted areas it shall be "classroom wainscot grey". The color stripes shall be ¾" wide and located as directed.

High-pressure steam—125 psi	Quadruple Blue
Intermediate pressure steam—40 psi	Triple Blue
Low-pressure steam—under 10 psi	Double Blue
Condensate return	Single Blue
City cold water	Single Yellow
Distilled water	Double Yellow
Recirculating water	Triple Yellow
Heating hot water supply	Double Orange
Heating hot water return	Single Orange
Domestic hot water supply	Double Green
Domestic hot water return	Single Green
Chilled water	Single White
Circulating lines common to hot and chilled water	Single White and Single Orange
Hot brine lines	Single Pink
Chilled brine lines	Double Pink
Circulating lines common to hot and chilled brine	Triple Pink
Sanitary waste lines	Triple Brown
Storm water waste lines	Double Brown
Vents	Single Brown
Gas	Single Aluminum
Low-pressure refrigerant	Double Aluminum
High-pressure refrigerant	Triple Aluminum
Compressed air	Single Tan

Acetylene	Single Light Green
Oxygen	Double Light Green
Hydrogen sulfide	Triple Light Green
Hydrogen	Quadruple Light Green
Ventilating supply ducts	Single Maroon
Ventilating exhaust ducts	Double Maroon
Ventilating air-conditioning ducts	Triple Maroon
Battery exhaust, fume exhaust, and exhaust gas	Quadruple Maroon
Fire hose lines	Single Red
Sprinkler lines	Double Red
Co$_2$ fire lines	Triple Red
Gasoline	Single Purple
Lubricating oil	Triple Light Blue
Fuel oil	Double Light Blue
Waste oil	Single Light Blue
Temperature-control system—heating	Single Magenta
Temperature-control system—ventilating	Double Magenta
AC electric conduits	Single Black
DC electric conduits	Double Black
Transfer conduits	Triple Black
Telephone	Quadruple Black
Low-pressure steam vent	Double Blue and Single Brown

room are covered with spaced layers of glass wool over which is an iron grid. Conservative calculation indicates that the larger room will absorb on impact over 98% of air-borne sound and mechanical vibrations from the outside.

The shops, which are in the basement, consist of the main departmental shop, the student shop, a student glassblowing shop and a woodworking shop (figure IV.9f). A stock room is located between the main shop and student shop. The floor in the main shop is of hard maple and all work benches are natural finish edge grain maple. Daylight illumination is enhanced by special refracting glass in the window sash which gives a fairly uniform illumination throughout the room.

Summary and Conclusion

At the time of building the Institute it was believed that the facilities would be adequate for many years. This soon proved to be a false assumption. The war projects and research taxed the space to its limit and postwar developments have seen little change in the pace. The approximate personnel distribution at the present time is given in Table IV.3.

3

REED COLLEGE LABORATORY

A. F. Scott

Reed College, Portland, Oregon

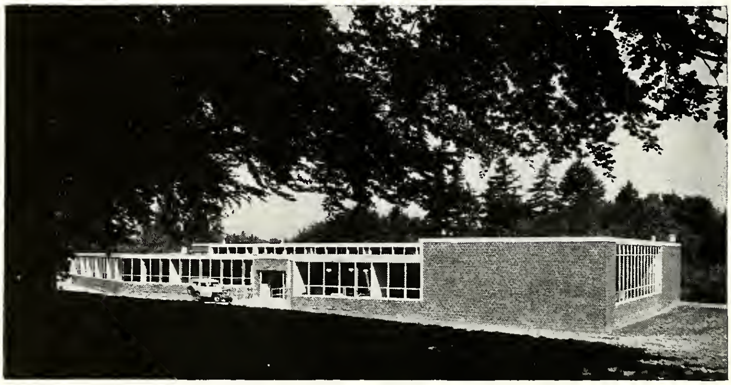


Figure IV.23 Reed College Science Building (Pietro Belluschi, Architect) Portland, Oregon.

About two years ago the staff of Reed College, Division of Mathematics and Natural Science, working with architect Pietro Belluschi, developed plans for a new science building. The proposed building is a one-story structure of modern design (see figure IV.23).

The building was designed with two important points in mind: the teaching requirements of the division and the need of economical construction. In line with these objectives there is a common center which contains the library and lecture rooms for the departments of biology, chemistry, and physics. Connected to this central unit are three wing-units which house the laboratories and offices for the three sciences. The shape of the building itself is determined largely by the contours of the site. By the use of one story, it was possible to raise the roof when the size of the room required it, and to keep low ceilings for the small thesis laboratory and office rooms. Certain general features of the construction of the building are noteworthy. The floor slab is placed directly on the ground; the only basements being a small one under the chemistry unit and another small one for the physics department. Under the perimeter of the floor slab is a continuous utility trench carrying all pipes except the drain pipes. This trench arrangement is intended to permit repairs, when needed, and it should also allow for any changes and improvements which may occur in the future.

The construction of the building follows principles that have for many years been found advantageous in the construction of industrial buildings. The windows are of factory type and the roof is supported by simple open-web beams which are left exposed. This type of construction in conjunction with careful planning made it possible to provide continuous windows around the outside of the building with clerestory windows in many of the rooms. In this way all of the large laboratories have two-directional natural lighting and ventilation.

In the late spring of 1948 funds were made available to start construction of the chemistry unit of the science

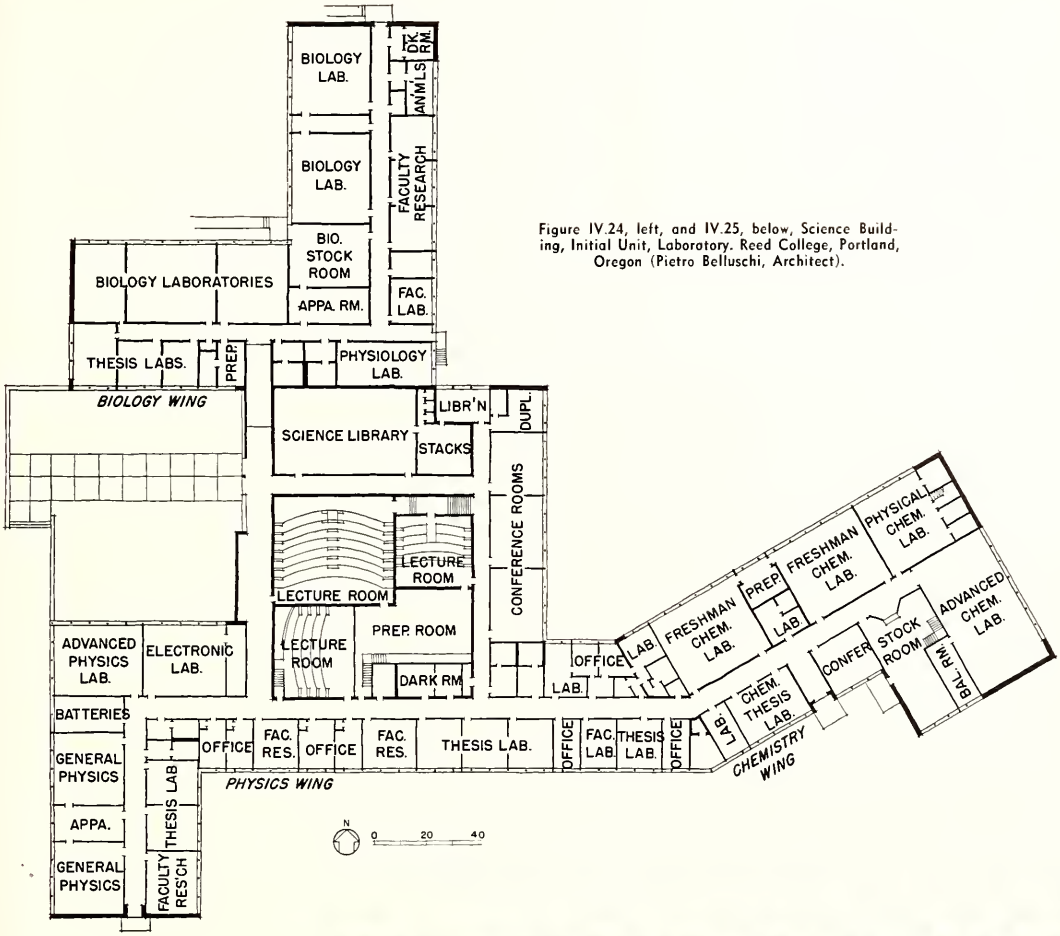
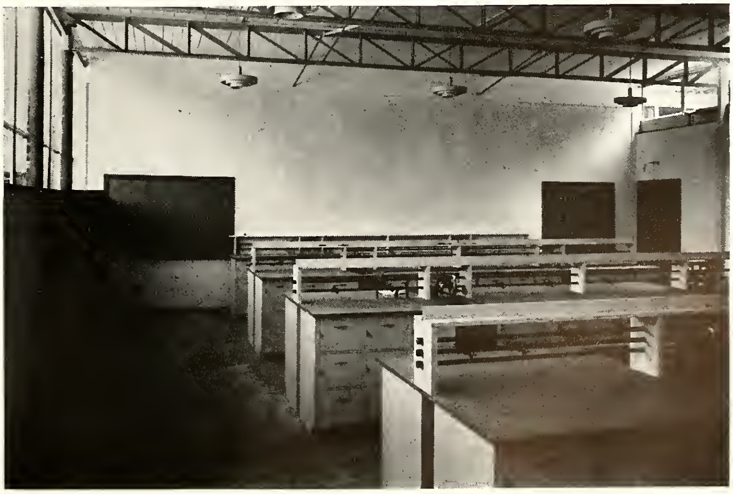


Figure IV.24, left, and IV.25, below, Science Building, Initial Unit, Laboratory. Reed College, Portland, Oregon (Pietro Belluschi, Architect).



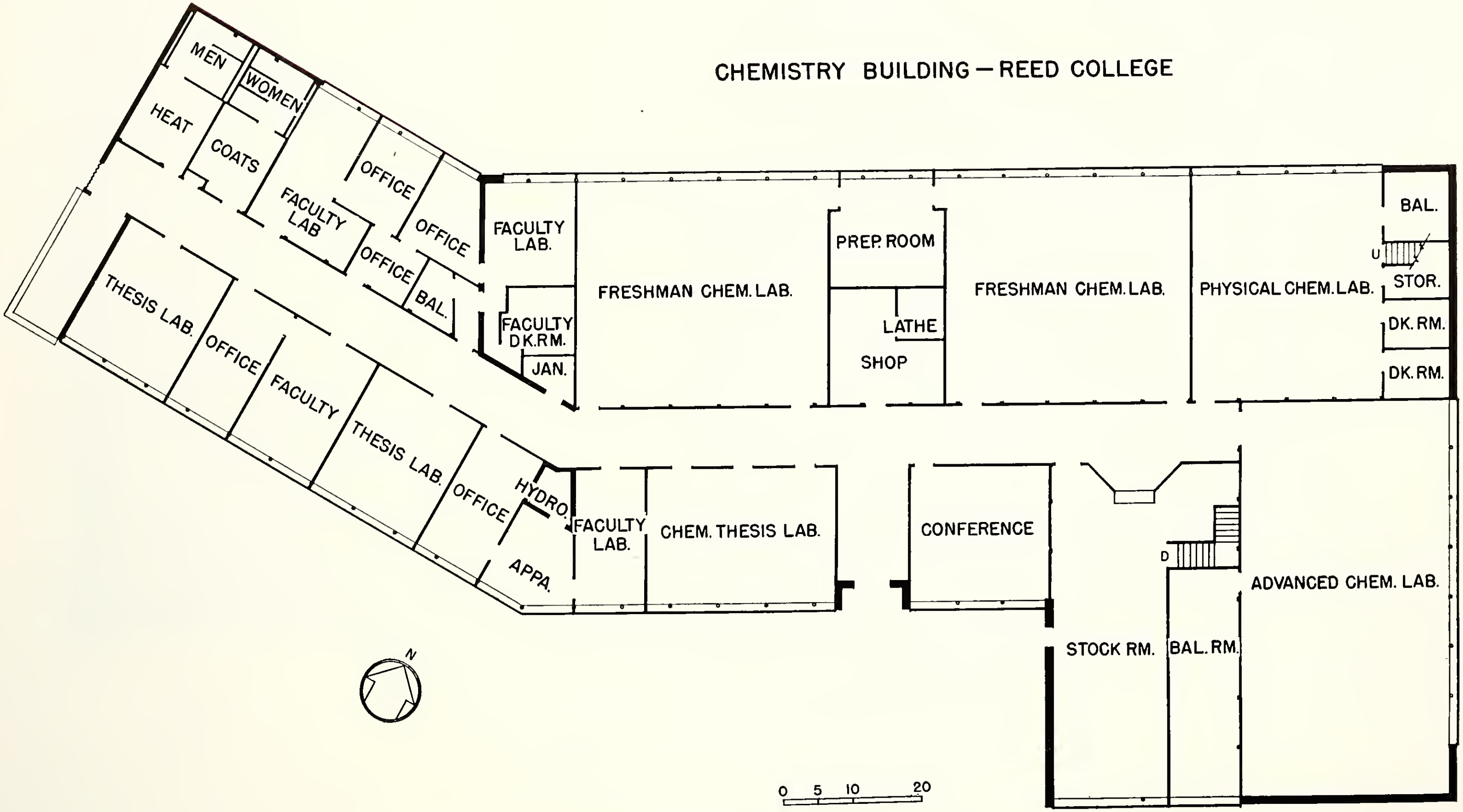


Figure IV.26 Chemistry Building, Reed College, Portland, Oregon (Pietro Belluschi, Architect).

building, and, as this is written, that unit is practically complete. The following notes will describe in some detail certain features of this unit and thereby also give more information regarding the construction of the building as a whole.

Undergraduate instruction in chemistry at Reed College is of two kinds: A. the customary instruction in the basic chemistry courses, and B. work on minor research projects, especially that required of seniors for their senior theses. This plan of teaching determined the layout of the laboratories. The laboratories for the basic courses are all at the east end of the building, farthest from the projected central unit and closest to the storeroom and the only classroom in the entire wing. These class laboratories all have 14-foot ceilings. In this section there is also a small shop. West of these laboratories and in the direction of the central unit is the low ceiling (10 feet 8 inches) part of the building in which are the various rooms for senior research projects and offices and laboratories for the four members of the chemistry staff. It may be noted in passing that one of the laboratories, designated as freshman laboratory in the original plan of the building, will be used initially for research under the Atomic Energy Commission contracts and that one of the senior thesis rooms will be used as a chemistry library until the rest of the building is built.

The laboratories for the different basic courses are all designed so that they have a full wall of windows along one side of the room and a row of clerestory windows on the opposite side. The desire to have this maximum amount of daylight was one of the strongest arguments for one-story construction. In the freshman and physical chemistry laboratories the full wall of windows (which are 7 feet high) starts 6 feet above the floor so that the wall can still be used as a backing for instruments. In the advanced laboratory, which is shared by courses in analytical and organic chemistry, the extra solid wall did not seem so important and consequently the window sill is 3 feet above the floor, giving a wall of windows 10 feet high. The achievement of so much illumination has been made possible by the extensive use of steel; for example, steel pipe columns to support steel roof beams, steel window sash, and so forth.

Heating of all the laboratories is by thin fin radiators in the wall, under the windows, over which the air in the room can circulate by convection. A damper arrangement permits fresh air from outside the building to be drawn in over these wall radiators whenever an exhaust fan in the room is in operation. The various pipes and conduits necessary to supply water, gas, air, and steam to the different laboratories are all located in a service tunnel around the periphery of the building. Drainage pipe, however, is of "Duriron" and is laid underneath the slab with a grade of not less than ¼ of an inch/foot.

The only basement in this unit of the building is under the storeroom. It is divided into two parts: one is for storage of chemicals, the other houses the air compressors and will also provide storage facilities for chemical equipment of various sorts. Space under the heavy concrete staircase has been converted into a small storage vault for radioactive isotopes.

4

DRAKE UNIVERSITY LABORATORY

William H. Coppock

Drake University, Des Moines, Iowa

Among the most modern science classroom buildings in the United States are the two units on the new Drake University campus, the Harvey Ingham Hall of Science and the Fitch Hall of Pharmacy. These buildings were designed by Saarinen, Saarinen, and Associates with the idea that the buildings would contain no costly, nonproductive, or purely decorative elements, but still be well proportioned and truly functional. Construction was begun in the summer of 1947 and the completed buildings were first used by classes at the opening of the spring semester of the 1948-49 school year. The total cost of the buildings with equipment was $1,400,000.

The two buildings were built as a unit, with an overall span of 387 feet including a 72-foot overpass. The Harvey Ingham Hall of Science is three stories high, 62'0" by 199'0", with a wing 70'0" by 110'0". The Fitch Hall of Pharmacy is two stories high, 46'0" by 142'0", and is set at right angles to the Harvey Ingham Hall of Science so as to form an L.

The first floor of the science building is devoted to laboratory work in anatomy, histology, and embryology, together with electronics laboratories, physics classrooms and laboratories, and a conventional stock room, reception room and offices for five. Each of the offices is equipped with private research facilities. Incidental rooms on the first floor include a physics shop, an instrument room, a power room and a photographic laboratory.

The second floor of the science hall includes two physical science laboratories and a stock room, two classrooms, four biological science laboratories and stock rooms, and office space similar to that on the first floor.

The third floor is devoted exclusively to chemistry, with the long center corridor running east and west. The general chemistry laboratory and organic chemistry laboratory are situated on the north side of the corridor with a stock room in between, whereas on the south side of the corridor are located the analytical chemistry laboratory, its balance room and supply room, the physical chemistry laboratory, a small classroom and offices similar in type to the offices on the other floors. The large laboratories for general chemistry and organic chemistry are approximately 76'0" by 24'0". Each contains nine laboratory tables 12 feet long with three hoods. The analytical laboratory is 60'0" by 24'0" and contains seven 12-foot tables.

The floors of the laboratories and supply rooms are cement, those of the offices, halls, and classrooms are asphalt tile. All rooms in both buildings are equipped with fluorescent lighting. "Duriron" pipe is used for the laboratory waste disposal system and distilled water is piped through block-tin lined pipe from a central source to each laboratory. Windows extend from the ceiling to within 3 feet of the floor on both north and south walls. Venetian blinds have been placed on the windows on the south side. The glass walls provide a great amount of natural lighting. Forced ventilation assures constantly changing air. Built-in clothes racks and

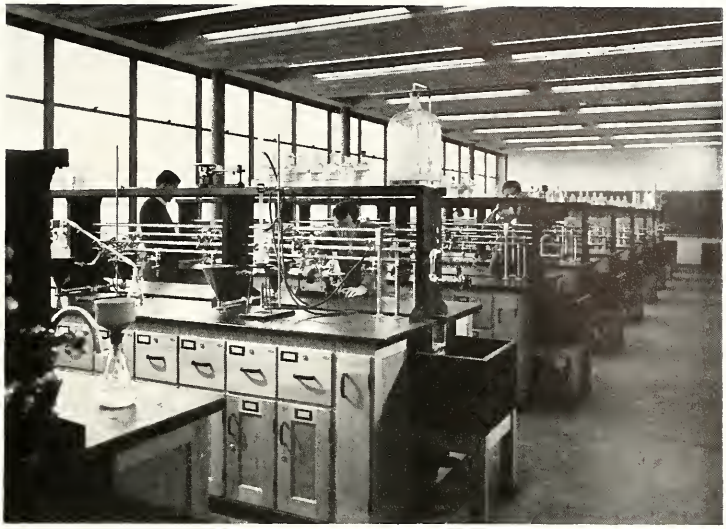


Figure IV.27 Teaching laboratories, Drake University, Des Moines, Iowa. The organic chemistry laboratory contains nine laboratory tables and can accommodate four sections of 54 students each. Fluorescent lighting and windows along one entire side provide a maximum of light.

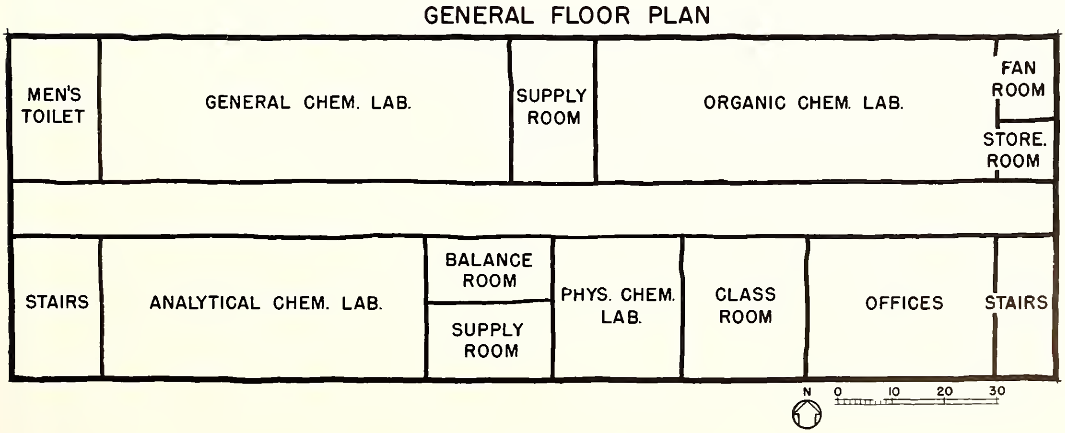


Figure IV.28 Floor plan, Chemistry laboratory, Drake University.

storage cabinets permit full use of floor space. Exhibit cases have been placed in the halls of both of these buildings for displays of materials of interest.

The wing of the science hall houses two lecture auditoriums so arranged that they may be emptied and refilled in four minutes. The larger auditorium seats 355, the smaller one 144. Acoustic plaster and indirect lighting have been used throughout the auditoriums. Seats are arranged in amphitheater style to provide a clear view of the lecture table. A casual visitor seeing the building for the first time is impressed by the clean lines, the effective use of color, and the fine ventilation and lighting. The laboratories are arranged following a somewhat standardized fashion. The inside wall contains the fume hoods, complete with "Kemrock" tops and accessories. Each of the larger laboratories has two exits on the same wall, and above each exit there is provided an emergency shower head. Storage cabinets are located below all hoods. The east and west walls of the rooms are devoted to blackboard space, whereas the outside walls are used for reagent shelving below the level of the windows. Between the pair of large laboratories is the supply room, serving them directly. The auditoriums include a number of unique features. The blackboards are white and the chalk used is black wax crayon. All of the lighting for the windowless auditoriums is provided from one of two systems, one fluorescent, the other spot lights shining down in the room. The intensity of the spotlights can be lowered so as to permit students to take notes during the projection of pictures.

THE CHEMISTRY DEPARTMENT

The chemistry department is on the top floor of the Harvey Ingham Hall of Science. Organic chemistry and analytical chemistry laboratories are shown herewith. There follows a description of the other elements of the chemistry department.

Organic Chemistry Laboratory

This room (see figure IV.27) contains nine oak laboratory tables with "Kemrock" tops, three forced-draft fume hoods, and open shelving for reagents. There is a blackboard along both the east and west ends of the laboratory. Each table has the following:

Lead lined drainage trough in center. "Kemrock" sinks at end.
Six straightway water cocks equipped with filter pumps.
One combination cold water bibb cock and stack steam mixing valve for hot water.
Twelve gas hose cocks.
Two double faced 120-v AC line-type receptacles.
Six individual steam baths using steam piped from boiler in basement.
Twenty-four drawer and cupboard combinations.
Table dimensions: 4'6" by 12'0" by 3'1" high.

Two emergency shower heads are located above the exits to the laboratory. The laboratory will accommodate a maximum of four sections of fifty-four students each.

Each fume hood has a six-place steam bath, gas, electricity, cup sink with cold water, and 120-volt AC electricity.

Supply Rooms

North Supply Room: The east and west walls are covered by adjustable wood shelving units, with the exception of dispensing windows to the organic and general chemistry laboratories. There is also a forced-draft fume hood with a shatterproof glass sliding door. Below the fume hood is a steam-heated glassware drying cabinet. The north side of the room contains a work table with "Kenrock" top and electric, gas, and water outlets. In the middle of the room is a double-faced storage bin. All shelving and bins are easily accessible by means of sliding ladders.

South Supply Room: Three adjustable wood shelving units are provided on the east, west, and north walls, and a double faced storage bin in the center. The work table on south side has a "Kemrock" top and services such as gas, water, and electricity. Below the work table are storage cabinets and drawers. Sliding ladders make shelves and bins readily available. An exhaust fan affords adequate ventilation.

General Chemistry Laboratory

The south wall contains three forced-draft fume hoods with "Kemrock" tops and such services as gas and water with a "Duriron" cup sink. Below the hoods are storage cabinets. Above each exit is an emergency shower head. Blackboards are located along the east and west walls. Open shelving for reagents is provided along the north wall below the level of the windows. There are nine laboratory tables each having the dimensions of 4'6" by 12'0" by 3'1" high and containing the following:

48 individual drawers with locks
Eight common property cupboards
Lead lined drainage trough and "Kemrock" sink
Six straightway water cocks
One bibb cock, same as in organic laboratory
Eight gas hose cocks
12 electrical outlets 120 volts AC

Analytical Chemistry Laboratory

The north wall of the analytical chemistry laboratory (see figure IV.29) contains two forced-draft fume hoods having gas, steam, electricity and water. Storage cabinets are located below the hoods and recessed in the wall. The south wall has open shelving below the level of the windows. Seven laboratory tables will accommodate two sections of forty-two students each. The accessories on each table are the same as those indicated for the tables in the organic laboratory. Emergency showers are located above each exit to the hall.

Balance Room

The balance room opens to both the analytical and the physical chemistry laboratories. Both the north and south sides of the room are lined with "Kemrock" tabletops which will accommodate a maximum of sixteen analytical balances.

Physical Chemistry Laboratory

The two laboratory tables will accommodate three sections of eight each. Each table has the following accessories:

DC and AC electricity.
Gas, air, vacuum, steam, and water.
Two cup sinks instead of the trough.

There is open shelving along the south wall below window level. Storage cabinets are recessed in the north wall and a blackboard is along the east wall. An emergency shower is located above the hall exit.

Class Room

The lecture table, with a "Kemrock" top, is provided with gas, water and electricity. Blackout curtains are used to darken the room for projection purposes.

Offices

Each office has a laboratory work table with a "Kemrock" top and sink. Gas, hot and cold water, air, vacuum, and steam services are provided for each table.

Figure IV.29 Teaching laboratories, Drake University, Des Moines, Iowa. The analytical chemistry laboratory, which can accommodate two sections of 42 students each, contains seven laboratory tables. Here again there is a maximum of lighting provided by fluorescent and natural light.

5

BATTELLE MEMORIAL INSTITUTE RESEARCH BUILDINGS

W. A. Welcker, Jr.

Battelle Memorial Institute, Columbus, Ohio

Battelle Memorial Institute was founded in 1923 by the will of John Gordon Battelle, whose early death interrupted an industrial career of many diverse interests. He had experienced difficulty in finding suitable facilities for the solution of many of the problems he encountered in his varied industrial contacts. His keen insight into the need for research facilities available to industry, and his generosity and desire to further the advancement of industry through scientific research and education, was manifest by the terms of his will. By its terms a nonprofit research foundation was created to carry on research and education in the fields of metals, fuels, and allied industries. Mrs. John Gordon Battelle, the mother of the founder, died in 1925, leaving the bulk of her estate to endow the Institute further. The Institute opened its doors for service late in 1929.

The endowment provides funds for buildings and permanent equipment as well as for the support of fundamental research and research education. Although a considerable amount of effort has been spent in this type of research, the major activities of the Institute have always been research for industry and, of recent years, for government.

There has been a steady and constant growth since the opening of the Institute in 1929 with a staff of less than thirty people in one building. Today the staff numbers 1300 occupying a total of nearly a half-million square feet of laboratories. The rate of research expenditure has rapidly risen from a few thousand dollars in 1929 to a figure in excess of $6,000,000 in 1949.

GENERAL FIELDS OF OPERATION

In the beginning the research efforts of the Institute were directed principally to metallurgical and fuels problems. The scope of the Institute's research has been constantly expanding since that time. The provision of facilities to meet the ever-expanding, ever-changing needs has presented many problems of space, arrangement, and facility capacity. In general, the fields of research endeavor today include: industrial physics, electronics, theoretical and applied mechanics, physical chemistry, organic chemistry, electrochemistry, fuels and combustion, ceramic technology, mineral processing, physical processes, ferrous and nonferrous metallurgy, high-temperature alloys, welding, foundry technology, metals and chemicals in agriculture, science and technology of the graphic arts, technical-economic surveys, and mechanical engineering research.

SITE

The location of Battelle in Columbus, Ohio, places its facilities within easy reach of many of this country's industrial centers, since Columbus is centrally located and has good travel facilities both by rail and air. This location is advantageous both from the point of view of ease of contact with industry and the accessibility of markets that furnish the many materials and supplies needed to carry on research operations.

The permanent laboratory buildings are located in a residential area close to the Ohio State University campus. The location affords a freedom from industrial dirt and heavy traffic vibrations. The nearness to the University enables a close cooperation between the two institutions.

In addition to the main location, the Institute has a six-acre industrial site located approximately one mile away, serviced by a rail spur, providing space for special pilot plants on a large scale and for agricultural test plots and greenhouse facilities. Rapid expansion of the research program and difficulties arising from construction material shortages in recent years have resulted in temporary use of leased space to house new divisions of research until more permanent quarters can be built. This allows a more thorough study of requirements to be made before permanent buildings are designed, thus providing experience useful in planning permanent quarters.

The ever-changing requirements of research have made it very difficult for Battelle to standardize on any one or even several standard types of laboratories. For instance, the space requirements and arrangements for research in printing plates are vastly different from those of process metallurgy, or the requirements for microchemical work, or fuels research with full-scale equipment, or agricultural research with growing plants. Not only do the many broad fields of research at Battelle require facilities of a different nature, but each of the specific fields needs many different arrangements of space and facilities to carry through from the test tube to semi-production stages.

In so far as possible, service laboratories have been set up at Battelle to carry a large part of the semi-routine work and service activities. These include photographic, metallographic, mechanical testing, heat treating, analytical, and x-ray laboratories, as well as machine shops, carpenter shop, and glass blowing shop. Research workers may either submit samples to these laboratories or call on these facilities for assistance.

PERMANENT BUILDINGS

The permanent buildings are located on three adjacent city blocks and cover about one half of the area of each of the blocks.

The architecture of the original building is classic in detail. As additional buildings have been added, this style has been modified, omitting the classic cornice and detail but still retaining a unity of mass balance and approximately the same fenestration spacing. These permanent buildings are of reinforced concrete and steel construction, with red brick facing and Bedford limestone trim. They are surrounded by extensive lawns, shrubs, and trees to give a pleasing setting and academic atmosphere.

All of the buildings are connected by pipe and service tunnels of sufficient size that they may be used by the staff in going from building to building during bad weather.

Since the buildings were built at different times and were designed to handle different kinds of work, each building is described as a unit. These buildings are designated as, and were built in the order named: King Avenue Building, Process Metallurgy Building, Tisdale Building, Fifth Avenue Building, and Seventh Avenue Building. The Agricultural Laboratory is located on a separate plot and is considered separately.

KING AVENUE BUILDING

The original King Avenue Building, the north and west wings of which were designed by Otto C. Darst, was built in 1928 and 1929 and has 90,000 square feet of floor space. It is an L-shaped structure approximately 160'0" by 200'0" with four floors and an attic. The attic space houses piping for the distribution of facilities and fans exhausting the hoods in the laboratories on the lower floors. Piped facilities are distributed from a loop of mains making a complete circuit of the outside perimeter of the attic, with feeders running down the inner face of the outside wall. Risers are spaced at approximately 24 feet, with each set serving two laboratories. Drain lines and return lines drop at the same locations as the feeders and collect in a 4'0" by 4'0" tunnel running completely around the building. In 1940, a five-story wing, 55'0" by 175'0", was added. This made the building a U-shaped structure having a total of 140,000 square feet.

The basement of the King Avenue Building houses a chemical pilot plant, tropicalization laboratory, store rooms for general supplies, x-ray laboratories, mechanical testing laboratories, machine shops, carpenter shop, large-scale fuels laboratory, creep laboratory, service machinery, electrical equipment rooms, telephone exchange, mail room, and fan rooms.

The first floor is occupied by a reception lobby, trustees' office, director's office, executive offices, library, museum, auditorium (seating 300 people), and a fuels laboratory.

The second and third floors are occupied by 85 single and multiple module laboratories and 35 offices devoted to corrosion research, instrument maintenance and repair, electronics, physics, photography, research chemistry, analytical chemistry, x-ray diffraction, electron-microscopy, spectroscopy, fuel-burning appliance research, calorimetric testing, constant-temperature rooms, paint research, flexible materials research, and first-aid room.

The fourth floor (attic) of the original part of the building is used for storage and distribution facilities. The fourth floor of the east wing includes a cafeteria and six chemical research laboratories.

The King Avenue Building has a 5-ton freight elevator serving all floors and a passenger elevator serving basement, first, second, and third floors. A small dumbwaiter also serves the main floors for deliveries. The large-scale fuels laboratory in the west wing has a section 50'0" by 30'0" with 35-foot head room and is served by a 5-ton crane. The chemical pilot plant

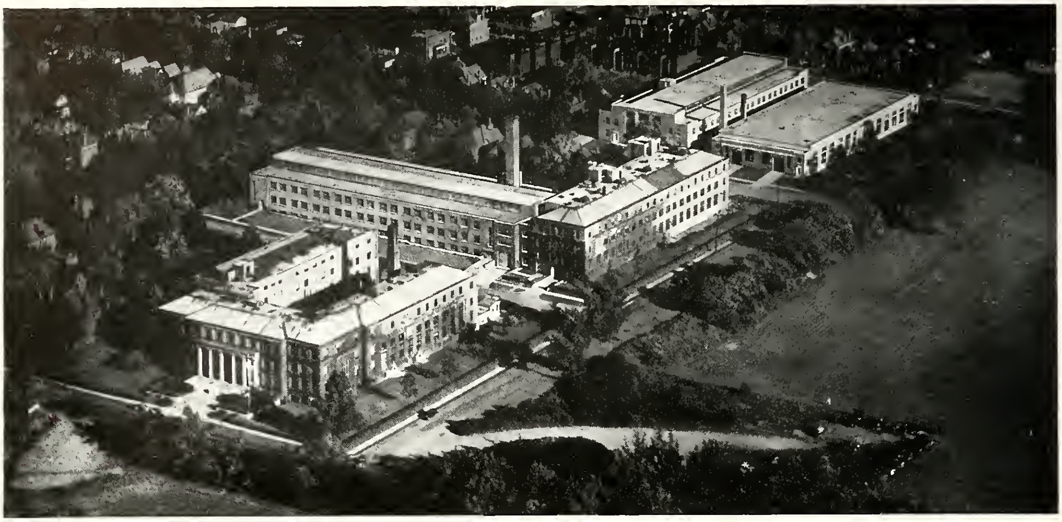


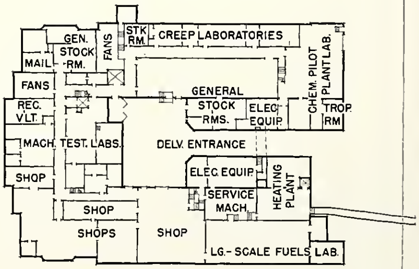
Figure IV.30 Aerial view of the principal buildings of Battelle Memorial Institute. These and auxiliary buildings provide approximately 500,000 square feet of office and laboratory space. They house 339 single-module laboratories, 80 multiple-module laboratories, 30 large work areas and 136 offices.

laboratory in the east wing has a section 25'0" by 54'0" with 23-foot head room and is served by a 2-ton crane. This laboratory is also equipped with a 12-foot wide by 14-foot high door for use in bringing in large apparatus.

Partition walls in this building are of brick in the basement and plastered gypsum block in the upper floors. All partition walls are nonload bearing and can be changed at will. The floors are covered by a troweled-on mastic in the laboratories, and the corridors are terrazzo. The use of mastic floor covering has been very satisfactory, since it is easily repaired when damaged or worn through.

The main lobby walls are of St. Genevieve rose marble and the floor of travertine. The library and auditorium are paneled in oak and have rubber and linoleum tile floors. The walls of the museum are lined with built-in glass-front display cabinets and its floor is of marble. The trustees' office is a reproduction of Gordon Battelle's office. The original paneling and furnishings were taken from his office and installed in the Institute. This section of the building preserves a monumental memorial atmosphere while the design of the remainder of the Institute is more basically functional.

Story heights for the King Avenue Building are set at 11 feet for basement, 13 feet for first floor, 12 feet for second and third floors, and 10 feet 8 inches for the fourth floor. The live load capacities for floors are 150 pounds/square foot for the original L-shaped part of the building for all above-ground floors. In the east wing this capacity was increased to 200 pounds/square



KING AVENUE BUILDING

foot for all but the fourth floor which is 300 pounds square foot. These heavier loading capacities allow the use of heavy machinery, such as roll mixers, digesters, kilns, presses, and ovens, so that both small and large equipment needed in a laboratory can be located in the same area.

PROCESS METALLURGY BUILDING

The Process Metallurgy Building is a five-story structure, 250 feet long, located in the block south of the King Avenue Building. It has a total floor space of 70,000 square feet and is devoted almost entirely to mineral and metal processing, from the beneficiation of crude ores to melting and casting of special alloys. Dan A. Carmichael was the architect who designed this and the remaining buildings of the Battelle Memorial Institute.

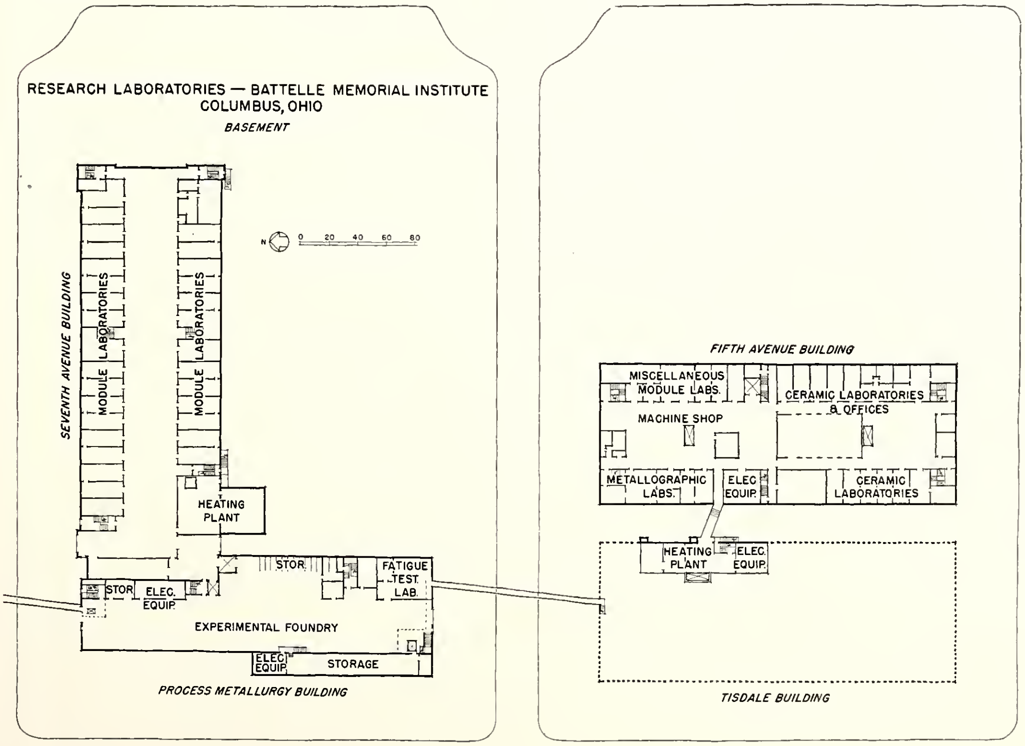
The first floor houses a complete experimental foundry for melting, casting, and cleaning of both ferrous and nonferrous materials. This area has 22 feet of head room. In this laboratory are located cupolas, electric-arc furnaces, induction furnaces, gas-fired pot furnaces, and crucible furnaces capable of handling melts of metal in any temperature range in open air, under vacuum or under controlled-atmosphere conditions. Charges may vary from a few ounces up to 500 pounds. Here complete equipment is installed for making sand molds, cores, etc., for the production of sand castings, precision castings, centrifugal castings, and ingots.

The entire foundry area is served by a 5-ton cab-controlled crane allowing easy handling of apparatus and heavy ladles or charges of metal. A special pit is built in the floor in front of each furnace so that large molds or ladles may be handily placed to receive the molten metal. These pits each have an adjustable platform which may be set at various depths in 6-inch increments. When not in use the platform is placed in its highest position and is level with the surrounding floor.

The foundry room has two large exhaust ducts running the full length of the room against the outer walls. These are of such capacity that better than 12 air changes per hour can be exhausted from the room. The ducts are equipped with openings every 10 feet in their length so that branches can be attached to vent special equipment.

The power requirements for electric furnaces are furnished from two transformer and generator rooms located one on either side of the foundry room. Special high-tension lines are installed as feeders to each piece

Figure IV.31 Basement floor plan.



of equipment having high current requirements. In addition to special lines, 3-phase, 220-volt and 110-volt single-phase outlets are located on the outer walls on approximately 12-foot centers. This arrangement provides readily available power for portable auxiliary equipment.

High-pressure air at 100 psi, natural gas at 15 psi and at 8 ounces, and city water are available at distribution points located every 24 feet along the outside walls.

The foundry floor is crossed by three tunnels allowing the various facilities to be brought up in mid-floor for special equipment.

Two large refractory-lined stacks are so located that they take out the hot gases from the cupolas and other fuel-burning melting equipment. These stacks discharge above the roof of the building.

A large storage area is provided in an adjacent basement for storing molds, flasks, patterns, furnaces and other special equipment used in the foundry. Storage bins for sand, melting stock and alloying materials are provided on the main foundry floor, so located that truck delivery can be made through chutes from the exterior of the building, and these materials are readily accessible.

A mezzanine floor, 148'0" by 30'0", is located along the south end of the east wall of the foundry room. A control room, machinability laboratory, foundry office, engineering materials laboratories, and cupola air conditioning and charging apparatus are located on this floor.

The second floor is devoted entirely to mineral processing research, including ore dressing, flotation, coal preparation, roasting, petrography, magnetic separation, and allied studies. Approximately 15,400 square feet are devoted to this work. One section of this floor, 55'0" by 33'0" has 22 feet of head room and is served by a 2-ton crane. In this section the remainder of the floor has 11 feet of head room. A 12-feet wide balcony midway between the floor and the ceiling is provided for two-level pilot plant operations. A large hatch in this area under the crane provides a means of bringing up bulky equipment from ground level. The entire floor is provided with drains and the floor is pitched at a slope of ⅜ inch/foot to facilitate the disposal of excess process water. Constant-head tanks are located in penthouses on the roof of the building and connected to this area with distribution pipes for use on low-pressure beneficiation apparatus. Outlets for 3-phase, 22-volt and single-phase, 110-volt electric power are located at intervals of 12 feet along the outside walls and on cross beams in the ceiling. Air, gas, water and steam outlets are located at 10-foot intervals around this outside wall.

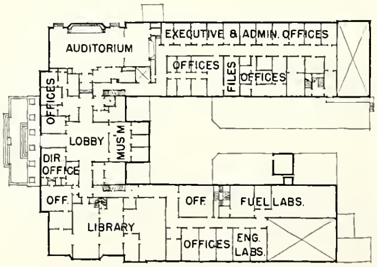
Seven small laboratories for special phases of this work, 13 staff offices, and a small equipment shop are located on this floor.

The third floor contains 21 laboratories and 13 offices devoted to small-scale metallurgical work. The fourth floor contains 13 laboratories and two offices principally used for plastic research. This floor also contains a specimen storage area of approximately 5000 square feet.

All floors are served by a 5-ton combination passenger and freight elevator. The first floor, mezzanine, and second floor are also served by a second four-ton freight elevator. The live-load capacities of the floors are as follows: first floor, no limit; mezzanine, 500 pounds/square foot; second floor, 300 pounds/square foot; third floor, 200 pounds/square foot; and fourth floor, 300 pounds/square foot.

SEVENTH AVENUE BUILDING

The Seventh Avenue Building, occupied in the fall of 1949, is located east of the north end of the Process Metallurgy Building and joining it. This is a 290'0" long by 100'0" wide structure with full basement, two first floor mezzanines—one on either side for the entire length of the building—and a full second floor. On all three floors individual laboratories are arranged along the outside wall for the length of the building. There are 103 laboratory module spaces. On the basement floor the space in the center of the building between



KING AVENUE BUILDING

the individual laboratories has a head room of 22 feet and is served by a 5-ton cab-controlled crane. This area is 38 feet wide by 260 feet long, with large truck entrances. The space above this area on the second floor also is pilot-plant space. It is covered by a monitor roof providing natural light and a head room of 21 feet and is served by a 2-ton cab-controlled crane. A hatch in the second floor under the crane and above the truck entrance allows an easy means of placing large equipment on the second floor. All floors are served by a 4-ton freight elevator.

Live load floor capacities for this building are unlimited for the basement floor, 200 pounds/square foot for individual laboratories, and 300 pounds/square foot for the second-floor pilot-plant area.

Framing of the building provides for eight refractory-lined stacks to carry out hot gases and discharge them above the roof.

Piped facilities are fed from mains circulating around the basement ceiling near the outside wall and risers are located every 25 feet. Each set of risers feeds two laboratory modules.

Electric power is distributed from six 600-ampere bus lines, one on each side of the building on each floor, distributing 220-volt 3-phase, 60-cycle current. Single-phase, 110-volt power is taken off these buses through dry-type transformers at appropriate intervals.

TISDALE BUILDING

The Tisdale Building is located in the block south of the Process Metallurgy Building. This building is 250'0" by 100'0". It is divided into two large work areas each 250'0" by 50'0". Eighteen control offices and small laboratories are located along the west wall on the first floor and mezzanine levels of one of these large areas. This entire building, with the exception of the offices, has a head room of 23 feet to the roof and 18 feet under roof trusses.

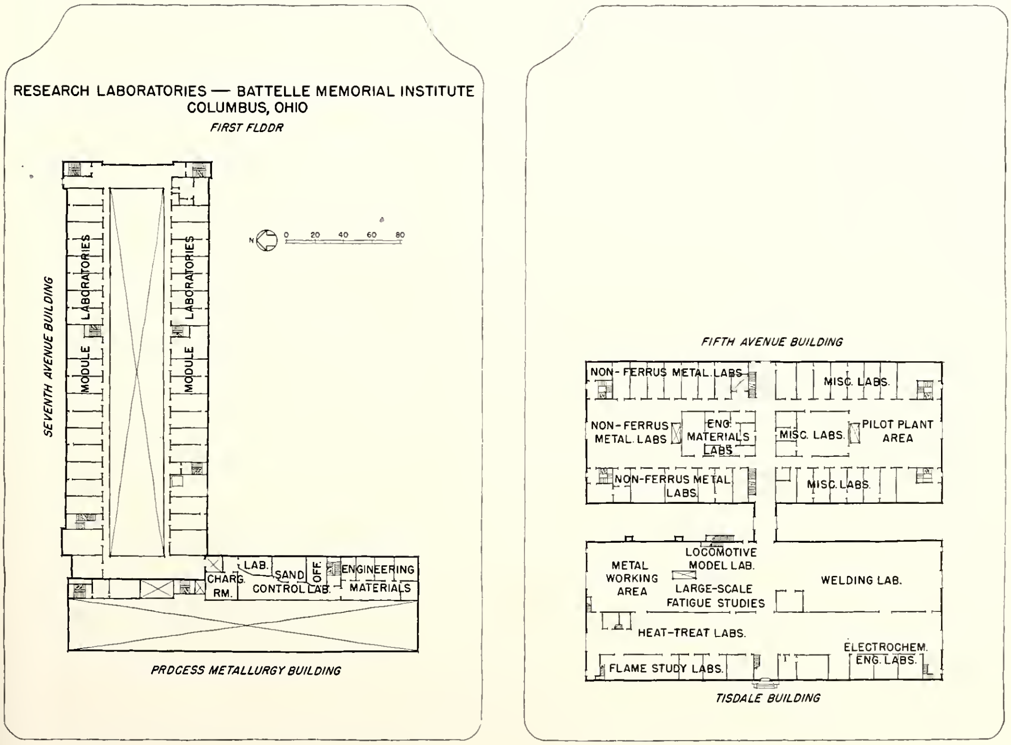
The west work area is devoted to two large laboratories, one for heat treating of metals and the other for electrochemical research.

The east work area is devoted to metal working (forging, rolling, swaging, wire-drawing, etc.), large-scale fatigue studies, welding research, and a locomotive model laboratory.

A small basement is located under a portion of this building, housing heating, power, and general facility equipment.

All piped facilities—air, gas, water, steam, etc.—are distributed through floor trenches. A main trench runs

Figure IV.32 First floor plan.



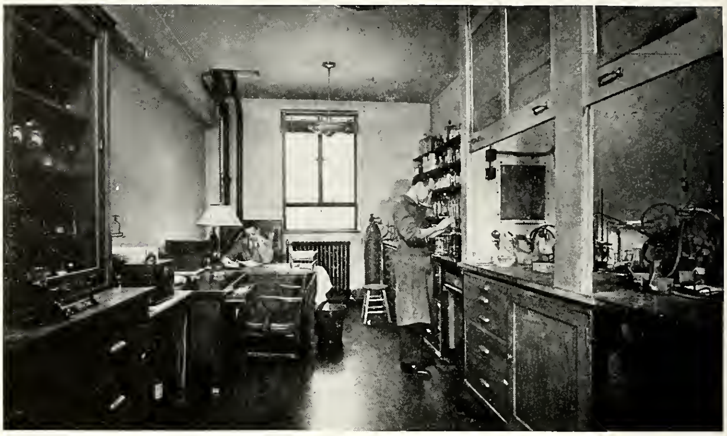


Figure IV.33 is a photograph of a representative module unit laboratory of the Battelle Memorial Institute. Each unit laboratory is equipped with a laboratory table serviced with compressed air, gas, steam, hot water, cold water, drains, safety shower, fume hood, single-phase 110-volt AC, and three-phase 220-volt AC. Some laboratories are equipped with additional facilities as needed, such as vacuum, distilled water, DC power and special gases.

the entire length of the building along the west side of the center wall and smaller cross trenches are located at 34-foot intervals connecting the center trench with continuous trenches running around the outside wall. These trenches are equipped with drains and are covered with steel checker plates.

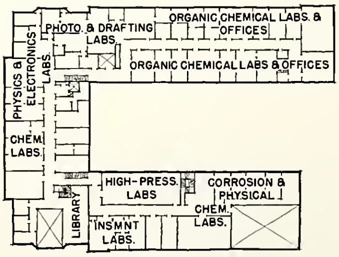
Electric power is distributed for general use through two 600-ampere, 3-phase, 220-volt bus branches. Single-phase, 110-volt power is distributed from 16 twenty-four-circuit panels, each serving equal areas. Special transformers for heat-treating laboratory power are located in the basement. Eight special generators and several rectifiers furnish the DC current required by the electrochemical laboratories.

The entire east area is served by a 2-ton crane and the roof truss design is such that a 2-ton load may be suspended from any panel point of the trusses. The entire area, except mezzanine offices, allows unlimited floor loading. Large truck doors are located at each end of both the east and west areas.

FIFTH AVENUE BUILDING

The Fifth Avenue Building is located east of the Tisdale Building and is connected by a 12-foot-wide passageway. This building is also 250'0" by 100'0". It has a full basement, first floor, and two mezzanine floors running the full length of the building, one on each side. A section of floor 102'0" by 48'0" in the center of the building connects the two mezzanines.

That portion of the building between the two mez-



KING AVENUE BUILDING

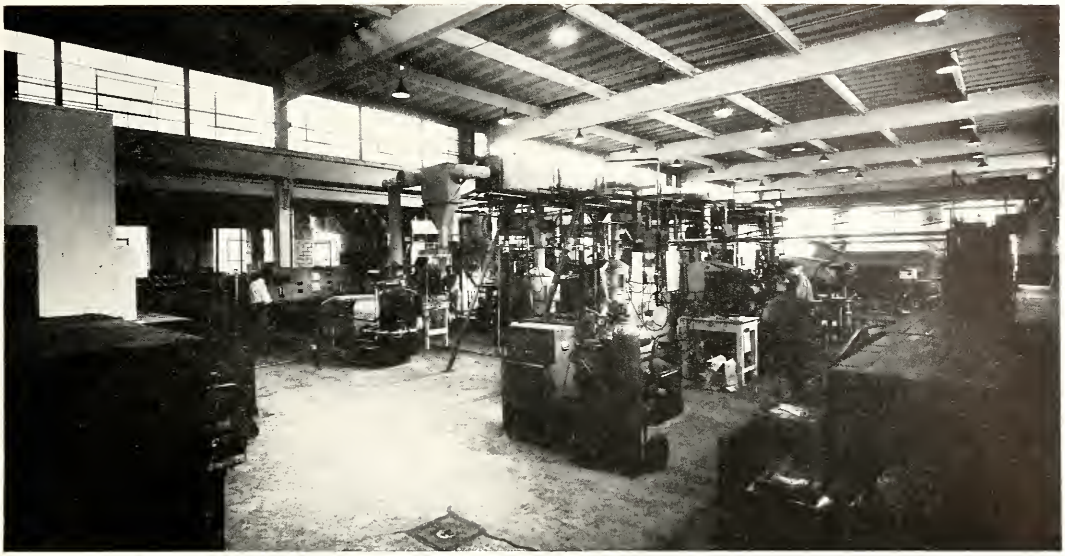
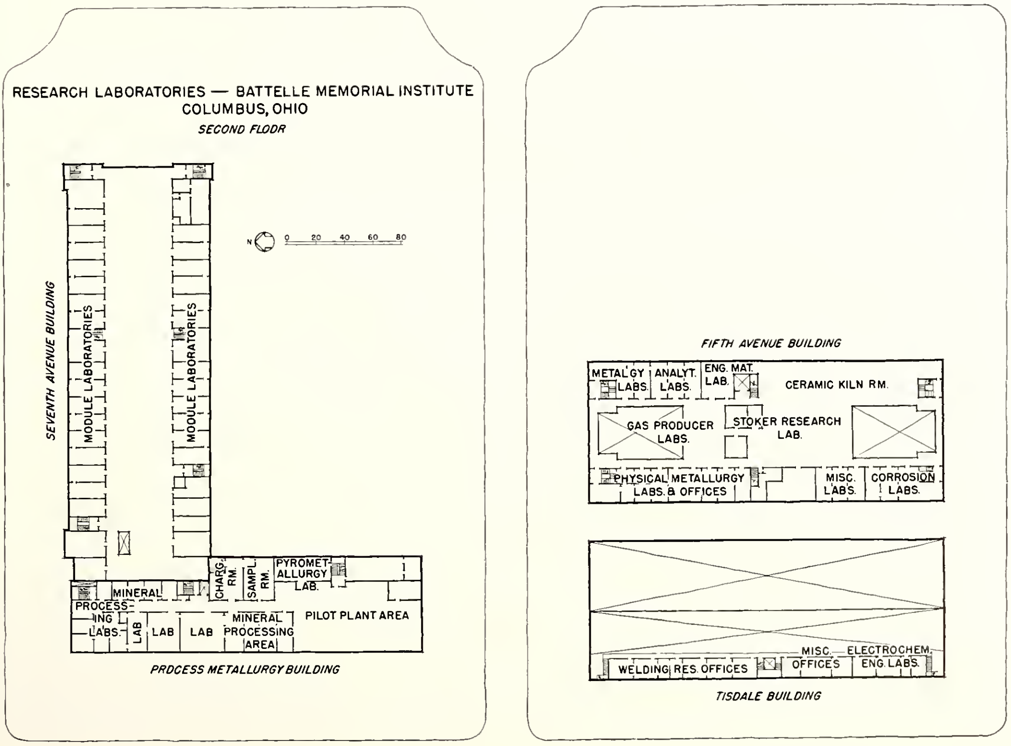


Figure IV.34 A section of the fuels laboratory on the second floor of the Fifth Avenue Building. This area is devoted to stoker development.

Figure IV.35 Second floor plan.



zanines has a monitor roof providing light and ventilation to the inner part of the building. This area is served by a 5-ton cab-controlled crane. There are two large hatches in the first floor under the crane for lowering large equipment into the basement. At each end of the building on the first-floor level is a large industrial laboratory approximately 74'0" by 48'0", with 30-foot head room. A large truck door serves each of these laboratories.

The basement floor has unlimited load-bearing capacity. The first floor slab was designed for 400 pounds/square foot live load, with supporting steel adequate for 250 pounds/square foot uniform loading. This allows the placing of heavy machines on this floor. The mezzanine floor is designed for 150 to 200 pounds/square foot load.

Four refractory-lined stacks are provided in the south half of the building, and the framing of the north end provides openings through the roof for four additional stacks as they are needed. These stacks are used to carry out the fumes and hot gases from special fuel burning equipment, kilns, and other sources.

Ceramic, metallographic, nonferrous, special metallurgical, fuels, electrical engineering, engineering materials, and miscellaneous laboratories are housed in this building. There are 72 laboratories and 24 offices, in addition to the pilot plant areas. Service departments, including glass blowing and machine shops, are also located here.

Each of the 72 unit laboratories, as well as the larger pilot plant laboratories, have compressed air, gas, steam, hot water, cold water, 220-volt, 3-phase and 110-volt, single-phase electricity and hood exhausts as required. The piped facilities are fed from mains placed in the basement ceiling and running near and parallel to the outside walls.

AGRICULTURAL LABORATORIES

Battelle's research in metals and chemistry has instigated a vital interest in the use of trace elements and industrial by-products in agriculture. Many of these researches are conducted in a special laboratory structure. This laboratory includes facilities for soil and produce chemistry studies, soil preparation, a greenhouse wing, and outside test plots.

TEMPORARY FACILITIES

The rapid growth of research activity has necessitated the use of several temporary buildings.

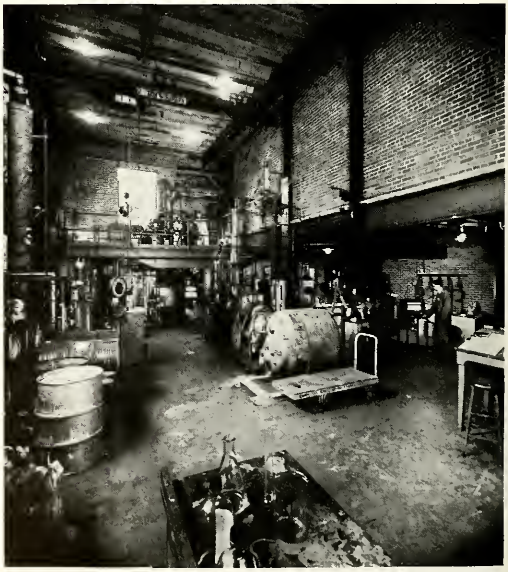
At present the Graphic Arts and Mechanical Engineering Research Divisions are occupying rented buildings. Additional leased space is also used for storage warehouses. Several former residences adjacent to the permanent buildings are used for offices.

STANDARD MODULE LABORATORY

The standard unit module laboratory is a room approximately 22'0" by 11'6" with a 3'0" by 7'0" door entering from a corridor at one end, and a window approximately 54 inches wide by 6 feet high at the other end. An "Alberene" stone-topped laboratory table is placed along one wall. This table is built on steel frames which support the stone tops independently so that storage cabinets can be set under the top between supports. This arrangement makes it possible to interchange cabinets. The top supports are so designed that they provide space for facility piping along the wall back of the storage space. They also support two wood shelves set above the table level against the wall. Air, gas, steam, water, vacuum and electrical outlets are placed above the bottom shelf. The tables measure 34 inches out from the wall and the stone tops are 25½ inches wide from front edge to a 3¾ inch curb supporting the bottom shelf. The shelves are 8½ inches wide. A ceramic sink 17" by 24" by 7" deep is installed in the approximate center of each laboratory table.

Cornell type "Transite" fume hoods are installed in three standard lengths—54 inches, 6 feet, and 8 feet. Each laboratory is equipped with one hood of the size required. Each hood is directly connected to an individual exhaust fan located on the building roof or in attic space. The exhaust ducts are fabricated of asphalt-covered sheet metal. The exhaust capacity for hoods is based on a maximum velocity of 100 feet/minute

Figure IV.36 Chemical engineering pilot-plant area in the basement of the King Avenue Building.



through the front opening of the hood and each hood is equipped with a damper to regulate the flow of air.

Three types of wood cabinets are installed under the laboratory tables. One type consists entirely of drawer space, a second type consists entirely of cupboard space and a third type has half cupboard and half drawer space.

Along the wall of the room opposite the laboratory table, office equipment and special laboratory equipment is placed.

Each laboratory is equipped with a safety emergency shower located over the entrance door. The shower is controlled by a quick acting positive valve located as near the light switch of the laboratory as possible. This location for the valve was chosen so that occupants of the laboratory can instinctively find it in case of emergency.

A floor drain is placed in each laboratory. All power outlets and light outlets are fed from separate circuits. Each laboratory in which fire hazard exists is equipped with a 15-pound CO_2 extinguisher. In all recently constructed laboratories a second door for emergency exit is placed in the wall opposite the laboratory table in the corner most distant from the entrance door. Inserts are placed in the ceiling of each laboratory on approximately 4-foot centers for the support of special equipment.

The Institute's many special laboratories differ greatly from the standard laboratories described above. These include constant-temperature, controlled-humidity rooms, dark rooms, tropicalization room, high-pressure laboratories, creep test laboratories, instrumentation and calibration rooms, x-ray and electron diffraction laboratories, and numerous others.

UTILITIES

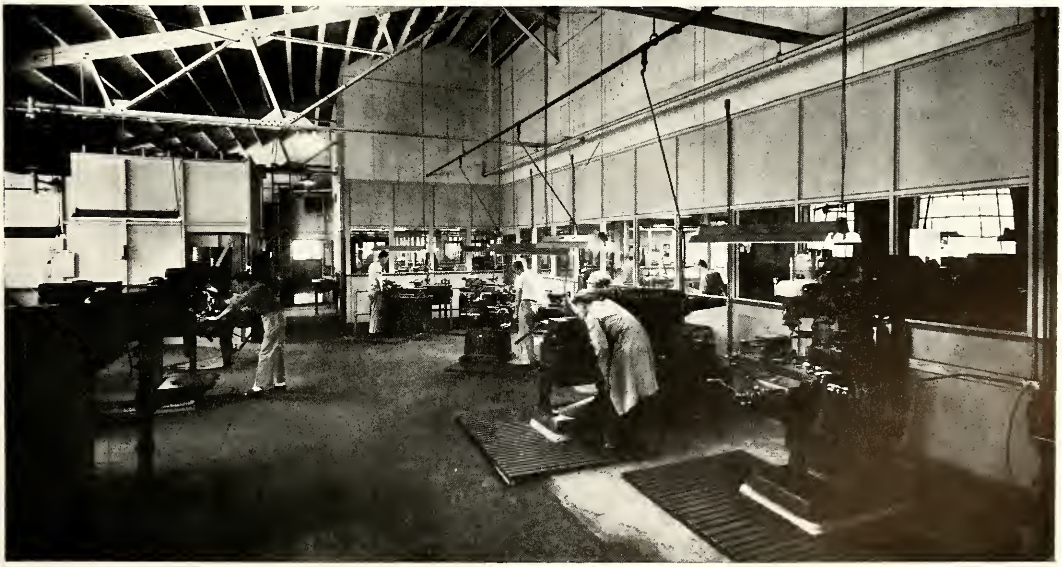
Electric power, natural gas, and water are purchased from the local utilities. The power company supplies two feeders: one, a 5000-KVA, 3-phase line at 13,200 volts, and the other, a 2000-KVA, 3-phase line at 4150 volts. Power distribution transformers fed from these lines are placed in each building and at special equipment locations.

Water is supplied to the buildings by two six-inch and two four-inch supply lines at 65 to 85 pounds/square inch pressure.

Natural gas is brought into the buildings by one 2-inch and one 4-inch line at 15-psi pressure. Pressure reducers are placed at various places in the buildings for supplying lower pressure gas as desired.

Both water and gas supply lines are connected from building to building so that failure of one supply will not close down operations.

Figure IV.37 This photograph shows a section of the mechanical engineering laboratory at Battelle. This laboratory is devoted to research in design and mechanical process improvement. It includes offices, drafting rooms, and complete model shops.



6

MELLON INSTITUTE RESEARCH LABORATORIES

H. S. Coleman

Mellon Institute of Industrial Research, Pittsburgh, Pennsylvania

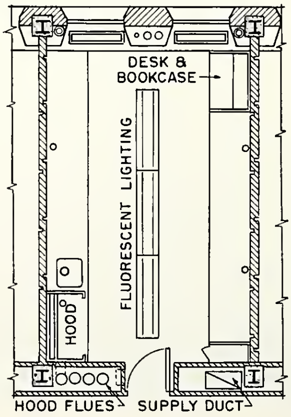
Mellon Institute is an endowed nonprofit institution, a corporate body, for long-range research in the pure and applied natural sciences, for training research workers, affording them opportunities for specialized development, and for providing technical information adaptable to public advantage.

The Institute's facilities are devoted primarily to basic researches in the fields of chemistry and chemical engineering. Its fellowship system, by which scientific investigations are conducted for a large number of companies concerned with widely varying types of problems, makes necessary the provision of many small laboratory rooms for the use of one or several fellows. In a company research organization, on the other hand, larger laboratories or movable partitions might be utilized advantageously and might have lower constructional cost.

The Mellon Institute building was erected during the depression period from late in 1930 to early in 1937. Architects for the original edifice were Janssen and Cocken. About 28% of the area for laboratories and offices in the structure was left unfinished at that time because of unanticipated immediate need for the space and to enable later construction of special facilities as required. The design work for completing the unfinished portion of the building during the past two years was done by the architectural firm of Hoffman and Crumpton. The contractor has recently concluded the construction and the building is now 100% completed.

The original constructional work was not carried out rapidly, and thus more than the usual time was available for study and perfection of the details of design and erection. Thirteen years' operation of the building has brought forth few suggestions as to how the design of the rooms and equipment could be better suited to the purposes intended, and the program of completion is proceeding largely in accordance with the original plans.

There are eight floors, the four upper floors containing the typical laboratories described here, the fourth or main floor the administrative offices and library, and the three lower floors the auditorium, special laboratories, shops, unit plants and mechanical equipment. The completed building contains about 175 laboratories and offices on the upper floors.



USE OF MODELS

Just as the architect used models of the exterior to determine architectural proportions, so the engineers employed models in designing the laboratories. A frame building was erected in which was constructed and completely equipped one each of the two types of standard laboratory rooms.

One of the first points brought to light was the visual appearance of the beam type of floor slab construction when the room contained fractional parts of bays, giving an uneven beam spacing on the ceiling. This discovery was made in time to change to the flat-arch type. The size of the small laboratory (consisting of one bay) was satisfactorily fixed by the column spacing of the building, but the division of space between laboratory and office in the two bays comprising the large laboratory suite had to be worked out in the model.

Special furniture, of wood or of metal, was built for these rooms by several manufacturers, embodying suggestions as to the best methods of providing flexibility, simplicity and utility. None of these, however, attained the goal set, particularly in regard to flexibility, and considerable original development was necessary before this problem was satisfactorily solved. The final result was a new type of laboratory furniture of extreme flexibility, consisting of a supporting structure composed of standard vertical and horizontal frames assembled without bolts, screws or nuts, and of removable cabinets of uniform size.

In this model laboratory were also evolved the vertical wall slots, adjustable shelf brackets, a method of supporting service and drain pipes from the wall slots, and a new wiring trough and turrets for the tables. Special pipe fittings were devised, eliminating a number of screwed joints, and ceiling light outlets were located. Here also experimental fume hoods were built of plywood and subjected to extensive tests, which led to a new hood design.

While the design of these standard laboratories was thought to have been well worked out on paper, it was found possible to make numerous improvements; and a practical means was created for getting helpful criticism from many laboratory workers who could not or would not study a drawing. The model laboratory building saved many times its cost; it certainly ensured a better design of finished laboratories.

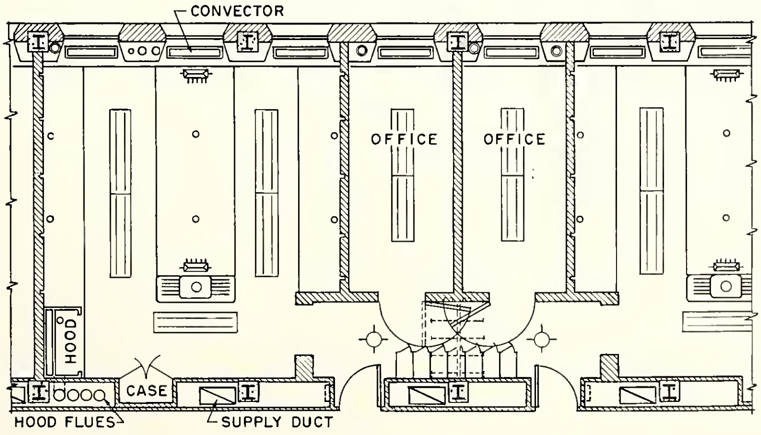
RESEARCH LABORATORIES OF THE INSTITUTE

Twenty years ago the concept of the module as a unit of space or design was new and in planning the Institute's building a bay was thought of as the unit of space. In terms of modules a bay may be considered as comprising two modules each approximately 6'6" by 20'0".

The typical research laboratories are in general of two sizes. There are a few variations from the floor plans (figure IV.38), some three-window laboratories being without offices and some two-window laboratories having offices. Each standard two-window laboratory occupies a bay or two modules of the building and includes laboratory tables along the side walls. The right-hand table is shortened at the window end to make room for a special laboratory desk. A built-in clothes locker is also included.

Each standard large laboratory with its adjoining office (three modules in the laboratory and one in the office) occupies two bays. The furniture consists of a wall table along each partition wall and a center table connected to the window wall, with a large sink on the free end. The large laboratories are, wherever

Figure IV.38 Floor plan, left, small laboratory, and right, large laboratory.



possible, located in pairs—one right- and one left-hand—with a common entryway and an entrance door for each laboratory. If it is desired to use the two laboratories separately, the entry is divided by a bank of clothes lockers. If the two rooms are to be connecting, the lockers are placed against the corridor wall, as shown in the floor plan, leaving a passageway. Recessed glass door cases for displays, storage of instruments, and other apparatus are set in the corridor walls of the large laboratories in the area which would have been used as an entrance door if the two bays had been utilized for two small instead of one large laboratory.

The small laboratories vary in width from 11'9" to 12'2¼", and the large laboratories from 17'3¼" to 17'11½". The depth of both types is the same and varies in different parts of the building from 18'10" to 19'2".

Constructional Materials. Glazed architectural terra cotta is used throughout the four laboratory floors and in most other parts of the building for corridor and room walls. The principal exception is in the case of the pilasters between windows and the walls beneath window sills in the standard laboratories.

The terra cotta blocks are cream or light buff color, semiglaze finish, varying slightly in shade to prevent monotony, 16" by 8" in size, and laid horizontally with a 3/16-inch mortar joint. The base course of all terra cotta walls is chocolate brown to match the dark Sienna marble used around certain windows in the corridors and as a floor in the fire-extinguisher niches. Blocks in partition walls are three inches thick, glazed on one surface only. A double-faced partition wall is therefore about 6½ inches thick. The jointing of the blocks was carefully done. Terra cotta is readily cut with an abrasive or diamond saw and sufficient cuts were made so that few blocks smaller than half size were used in the walls. Special shapes were used where required to prevent unsightly jointing. In the entryways of the large laboratory suites blocks with a depression or pocket to receive the knobs of the office doors were employed (figure IV.38), to give the maximal space for passage where the rooms are en suite.

Wall surfaces of glazed terra cotta are particularly appropriate for use in laboratories because they are easy to clean and free from attack by ordinary laboratory fumes. Cleaning is facilitated by the use of external and internal rounded corners and a cove-base course. In a glazed block wall it is desirable to use units of large size so that there will be as few mortar joints as possible. Such joints darken from wall washing and in time mar the beauty of the wall.

The window ends of the standard laboratories, composed of the pilasters between windows and the wall beneath the window sills, are constructed of removable "Transite" panels, ½-inch thick, finished with "Vinylite" paint to match the terra cotta and trimmed with aluminum molding strips. These panels conceal all service distributing pipes, drains and conduits, yet render them readily accessible for repairs.

The laboratory floor is of course subject to more use and abuse than any other part of the room and hence the choice of a suitable material for this purpose has always been difficult. The ideal laboratory flooring material should have resistance to acids and alkalies, insolubility in organic solvents, freedom from indentation, and resiliency. No material possessing all these properties is known to the writer. Asphalt tile and mastic have been extensively used, but meet only the first requirement satisfactorily. Cork and rubber make the most resilient floors, but fall short on resistance to acids and alkalies and insolubility in organic solvents. Ceramic tile, although not resilient, possesses the other properties to an admirable degree, and was therefore chosen. The tile are 6 inches square by ½ inch thick, of a buff color and totally impervious. They are laid with a narrow mortar joint composed of high-silica cement, which is more resistant to acids than ordinary Portland cement. If acid is spilled on the floor, the joint can be regrouted. To provide resilience, loose corrugated rubber or link mats are used where needed.

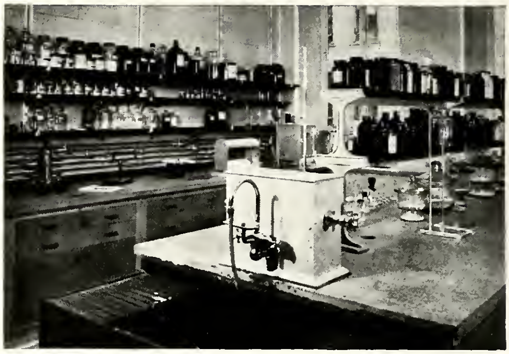


Figure IV.39 Large laboratory.

The laboratory ceilings are plaster, painted with "Vinylite" paint. Diamond metal mesh was first secured to the tile slab and then scratch and brown coats of mortar composed of neat gypsum wall plaster were applied. The finish or skim coat consisted of properly soaked hydrated lime and pure white gypsum gauging plaster. This type of ceiling finish was selected after extensive tests with many types of plaster. It was found that, with the metal mesh, common patent or gypsum plaster could be used with less likelihood of falling, if soaked with water from the floor above, than any of the more expensive cement plasters. Furthermore, gypsum plaster does not craze and crack as do cement plasters.

The windows in the laboratories and throughout the building are made of alumilite-finished aluminum extruded sections and glazed with ¼ inch polished plate glass.

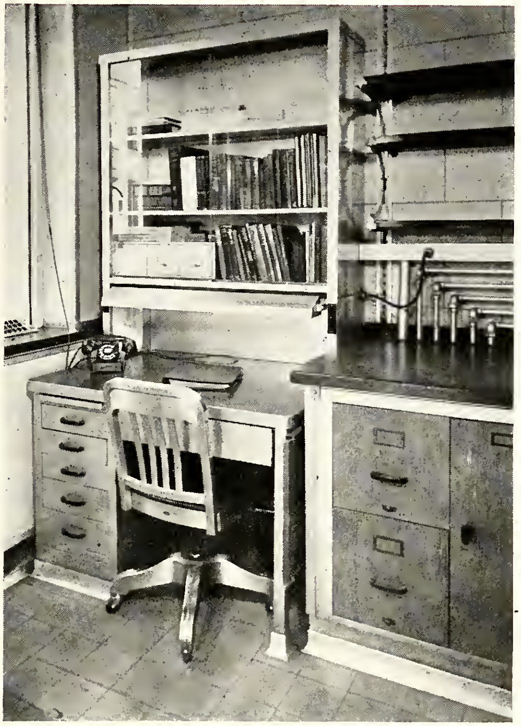


Figure IV.40 Laboratory table.

The windows in the laboratories consist of two outwardly swinging casement sashes, latching to a permanent mullion, beneath which is an inwardly swinging sash hinged at the bottom. The lower sash is held in any position by a friction device and admits air to the room without creating a draft, which would disturb a Bunsen flame on the laboratory table. The casement sashes are controlled by a worm-and-wheel crank-operated device that will hold them open even against a strong wind, and are locked in the closed position by a lever handle on the center mullion that operates bars engaging three lugs on each sash. A handle in the center of the upper side of the lower sash locks this sash by turning through an arc of 90°.

Careful attention was necessarily given the window-operating devices which must be capable of operation from the sides of the center table in the large laboratories (figure IV.38). The windows are sealed by double felt strips and are very tight against infiltration of air. As the windows are only slightly more than 3 feet wide, they are readily cleaned from the inside by opening one casement at a time, the mullion providing a firm hold for the cleaner.

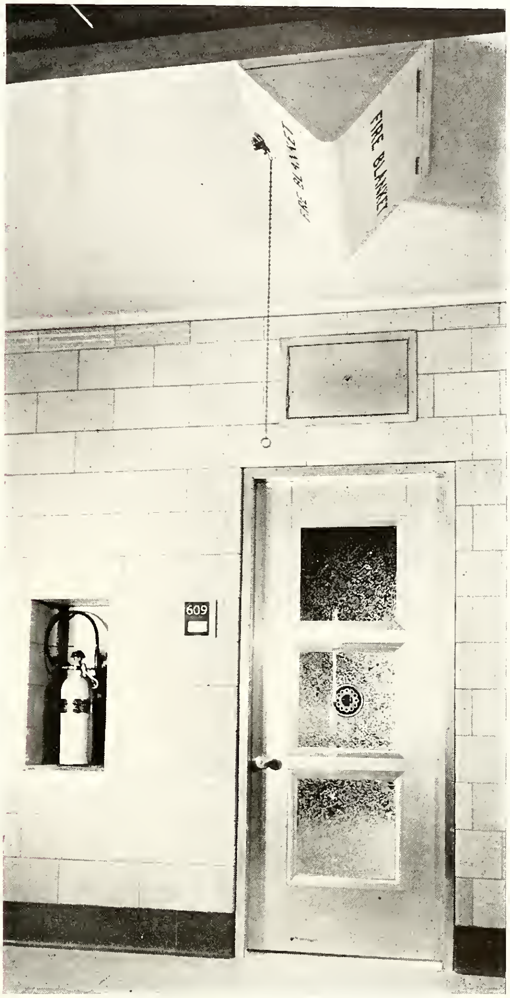


Figure IV.41 Door, fire-blanket box, and fire-extinguisher niche.

The laboratory doors and frames (figure IV.41) are also made of alumilite-finished aluminum. The stiles are hollow extruded sections, 7½ inches wide and 1¾ inches thick. There are three panels of equal size glazed with ¼ inch glue-chipped plate glass. In the center panel of the corridor doors is a reproduction of the symbol used by alchemists to designate their laboratories. These emblems are practical as well as appropriate. They are located low enough in the door to preserve privacy, yet they enable anyone desiring entrance to determine whether work is in progress which should not be interrupted. The door butts and the exposed parts of the lock, including the knobs, are also made of aluminum.

Structural Provisions for Ventilating Ducts and Service Risers: In the design of the floor slabs, slots about 15 inches wide were provided for the installation of vertical ducts and pipes in the wall between the laboratory and corridor, and in the wall at the window end of the room. Through the first-mentioned slots are carried the fumehood flues and also ducts for supplying dust-free air to the laboratories. The slots at the window ends accommodate the drain stacks, roof conductors, heating risers and returns, vertical supply pipes for water, gas, air and vacuum, and such other supply pipes as may be necessary. At the attic floor, the corridor wall slots are sealed around the ducts and flues with concrete. The window-end slots are covered with removable steel plates, so that there can be no draft if a panel is broken during a fire in a laboratory. If a flood occurs in the attic, water is prevented from flowing down the slot by a steel curb-angle fastened to the floor, bedded in mastic. Because the hollow wall at the corridor end of the room is permanent, being made of terra cotta, the ducts enclosed therein must be composed of the most lasting materials. "Armco" iron, well-protected inside and out with asphalt paint, was used for the fresh air ducts, and chemical stoneware for the fumehood flues. These flues are 8 inches in internal diameter. Because of lack of space for joints of the bell-and-spigot type, the ends of the flue sections were ground square, and the joint was made by bolting around the pipe a metal band 2½ inches wide and ¼ inch thick after the ends of the pipe had been bedded in mastic. Enclosed in this hollow wall are also conduits for carrying wires to the laboratory panel box at the entrance door and for the hood fan motor control.

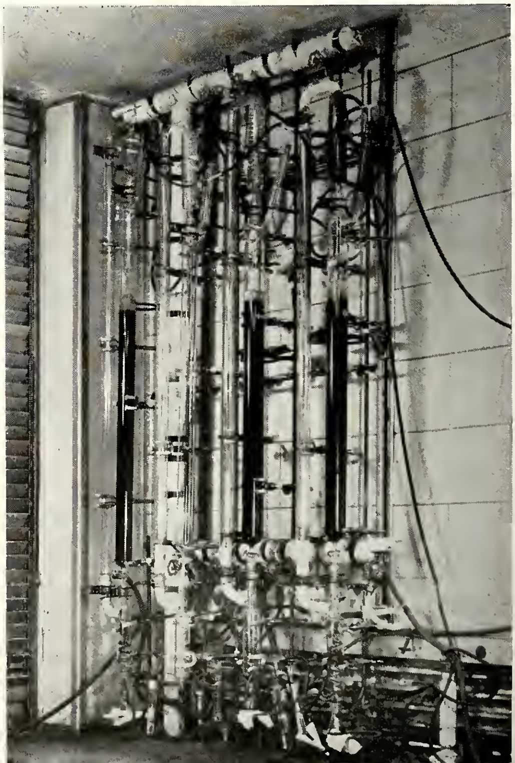
The wall at the window end of the room consists of removable "Transite" panels and aluminum molding strips. Besides the vertical supply pipes, it conceals the horizontal distribution pipes to which are connected the service lines on the laboratory tables. Back of these horizontal pipes, under each window, are the cast-iron convector-type radiators. The window stools, which are at laboratory table height, are made of the same material as the tabletops. Over each radiator is a grille, V-shaped so that the heat cannot be closed off by piling books or other objects on the window stool.

Available in the attic are high-pressure steam and air which are not ordinarily supplied to a laboratory, but by the use of the floor slots and removable panels can be brought easily to any room. The attic may be reached from all floors through a large pipe shaft, and accordingly any additional service required in the future may be carried to the attic and thence to any laboratory. This feature contributes to the great flexibility of the laboratory layout at Mellon Institute.

Vertical Wall T-Slots. Among the novelties developed and first used by the Institute are the vertical T-slots extending from floor to ceiling in the walls of the laboratories and in many other rooms. Figure IV.42 shows in cross section the shape of the slot and how it is built into the wall. The flanges of the steel wall stiffener to which the T-slot is attached by machine screws extend between the backs of the terra cotta blocks comprising a double-faced wall. The T-slot itself is an anodic-finished extruded aluminum section with ½ inch holes, on 1¼ inch centers in the back for supporting the shelf brackets, and having screw holes for attaching to the stiffener. Under the heads of the cadmium-plated attachment screws are fiber washers to prevent possibility of electrolysis between the steel and aluminum. The distance between T-slots is in multiples of half terra cotta blocks (8 inches) and varies from 25 to 49 inches, center to center. The dies used in extruding the aluminum T-slots and casting the shelf brackets have been released for general use, and this feature has been applied in several other laboratories.

Figure IV.42 also exhibits a section through typical center- and wall-type laboratory tables with shelf brackets, wiring trough, service lines and drain supported by the T-slot. The laboratory wall table itself is clamped to the wall by means of the T-slot. Figures IV.43.a, IV.43.b, and IV.43.c are photographs of special distillation laboratories, illustrating how the wall slots may be used to support an elaborate setup of chemical apparatus. With these slots available, it should never be necessary to drill the terra cotta to attach equipment of any kind.

a



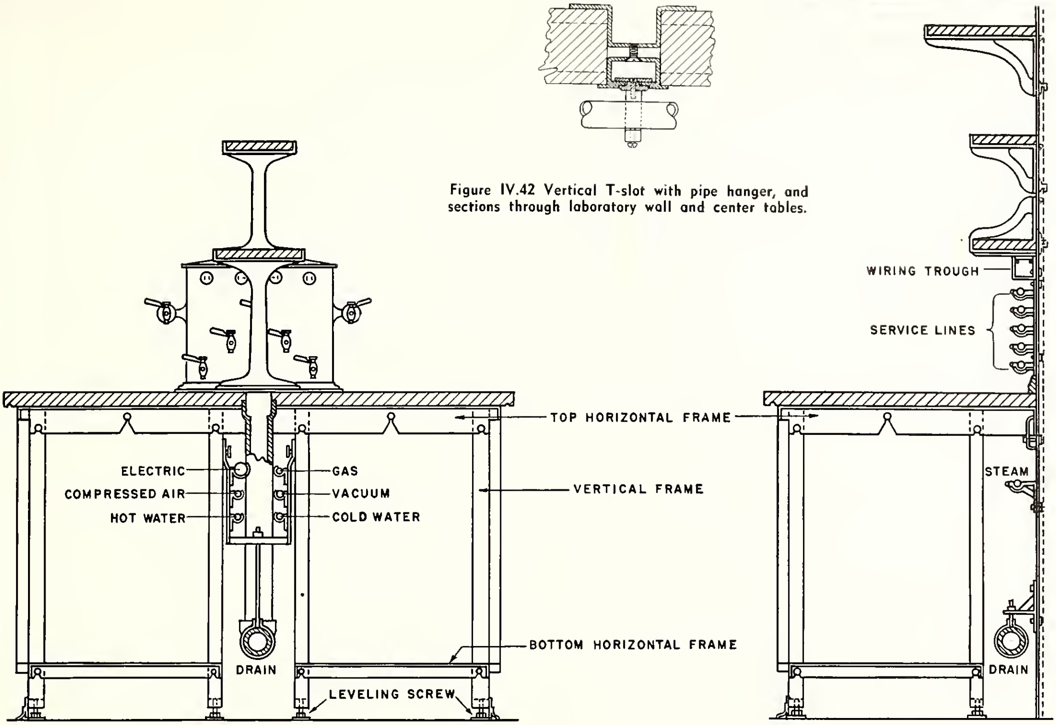
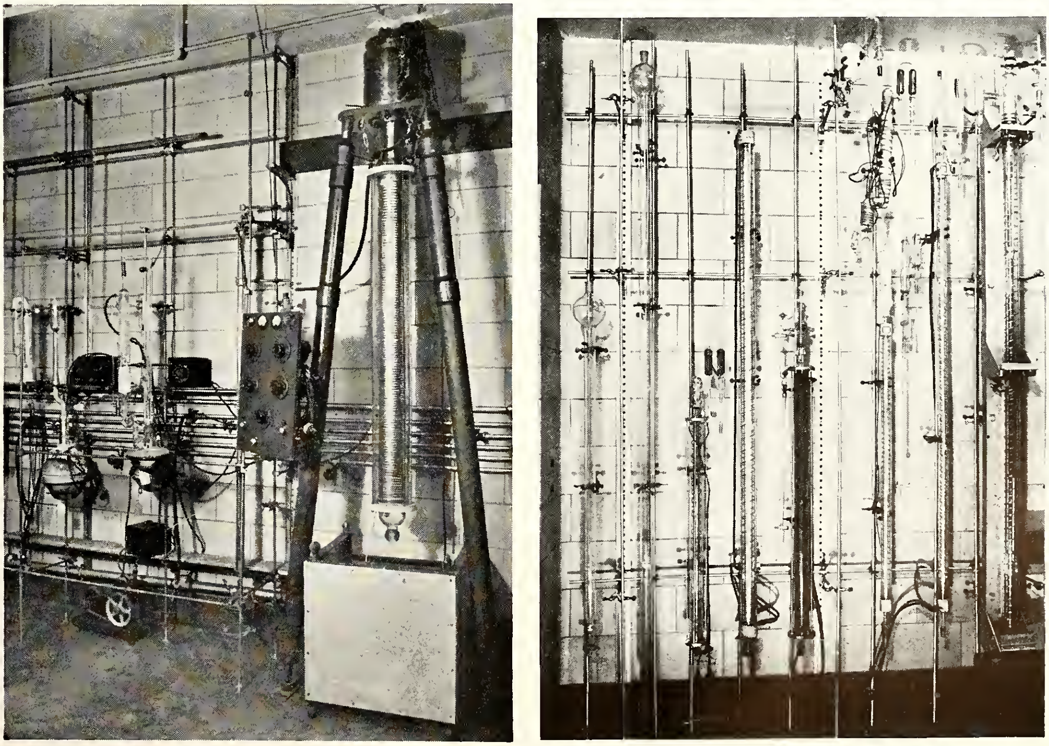


Figure IV.42 Vertical T-slot with pipe hanger, and sections through laboratory wall and center tables.

Figures IV.43 a, b and c Three photographs showing the utility of wall T-slots.



b

c

Plumbing Services. Each laboratory is provided with outlets for hot, cold and distilled water, steam, compressed air, vacuum and gas. Copper pipe and tube is used for hot and cold water, aluminum for distilled water, and black steel for air, vacuum, gas and steam. The smallest size of pipe used is ½ inch. In the center-type tables, the pipes are carried under the tops on hangers held by the lugs on the back of the vertical table framing members. The outlets on the center tables are in the form of anodic-finished aluminum turrets, located on the table ends and containing electrical outlets and the services mentioned. The turret on the free end of the table also contains the hot and cold water faucet for the double drainboard sink. The faucets for the sinks in the wall tables are supported by the service pipes above the tabletop. For obvious reasons, the distilled water outlet is not placed over a sink, but directly over the tabletop. Two outlets for steam are provided on the wall table—one in the hood and one near the sink. The steam service line is carried entirely beneath the tabletop, except where it is brought through the top for wall table outlets or to the turret on the center table. All stopcocks are of a white metal alloy, not plated, and are equipped with colored "Plaskon" indexes. Special combination offset elbows and unions are used at the window ends of service lines on wall tables, an arrangement conducive to easy removal for cleaning or alteration.

Drains, both vertical stacks and horizontal lines in the laboratories, are of chemical stoneware. The joints are the conventional bell-and-spigot type sealed with a hot-poured asphaltic compound. A vented ceramic trap is installed for each table at the point where the horizontal drain enters the stack. To decrease the possibility of stoppage, the stacks themselves contain no horizontal runs; they are vented through the roof. The horizontal drain lines under the first floor are made of "Duriron."

The laboratory drainage system is entirely separate from the sanitary system. The two systems are connected outside the building and the laboratory system is protected from sewer gas by a master trap vented to the roof.

Ventilation. All rooms in the building are supplied with fresh air from which the dust has been removed by electrostatic precipitators. During the heating season air is tempered and humidified. The exhaust is through fume hoods and toilet rooms and from the corridors. The rapidity of air change varies in different parts of the building and is ample for good ventilation.

Electrical System. The AC electricity distribution is accomplished by the 3-phase 4-wire system.

There are three phase wires and a neutral; and to simplify the balancing of the permanent electrical load on the three phases, these wires have been color-coded throughout—red, yellow and black for the phase wire, and white for the neutral. Between any phase wire and the neutral the potential is 120 volts; and as there are three phases and the voltages add vectorially at a phase angle of 120°, the potential between any pairs of phase wires is $120 \times \sqrt{3}$, or 208 volts. AC voltages available, then, are 120 volts single-phase (between neutral and a phase wire), 208 volts single-phase (between two phase wires), and 208 volts 3-phase (between three phase wires). The fact that the 3-phase voltage is 208 instead of the customary 220 is not a serious objection because 220-volt motors will operate satisfactorily on 208 volts, and both heating and rotating equipment designed for 208 volts is available. If 220 volts must be had, suitable step-up transformers may be used; this occasional necessity for utilizing transformers is of no moment when one views the many obvious advantages of the system.

The circuits are brought to the standard laboratories through conduits in the hollow corridor walls. In the corridor over each laboratory door is a pull box where connections are made to the feeders for the laboratory panel box, which is located just inside the laboratory door. This panel box contains a 50-ampere main "De-Ion" circuit breaker, a watt-hour meter, and individual "De-Ion" circuit breakers for the lighting and laboratory table circuits. The operating handles of the individual circuit breakers for lights project through openings in the panel box door and therefore serve as switches as well as breakers. When a breaker trips, owing to an overload, the operating handle drops to a position intermediate between "off" and "on"; and, as soon as the cause of the overload has been removed, it is only necessary to throw the handle to the off position and then on again to restore service. The capacity of the individual circuit breakers for lighting and single-phase table circuits is 15 amperes, and for the 3-phase table circuit 25 amperes per phase. In some cases it has been necessary to install larger breakers.

From the laboratory panel box, conduits are run under the floor to the space back of the removable "Transite" panels at the window end of the room. From there the conduit is carried, like the plumbing service pipes, through the tabletop, to wiring troughs fastened to the wall T-slots over each wall table, and to the turrets on the center table. The wiring trough, a new feature in the Institute's equipment, consists of an extruded anodic-finished aluminum trough measuring 2½ inches square in section, with a snap cover to close the top. Holes are provided in the front face on about 21 inch centers for receptacles installed on the inside of the trough and requiring no finish plates. A majority of the receptacles are for 115 volts single-phase, but many are connected to all four wires of the system, thus providing any of the three types of current mentioned. The wiring trough is much superior to the usual conduit and fittings, in that it is only necessary to remove the cover to find the source of any trouble arising within the trough or to make changes in the receptacles.

In addition to the receptacles in the wiring troughs and turrets, there are two single-phase and one 3-phase receptacles in the fume hood, with control switches on the outer end wall of the hood. The corridor wall of the large laboratories also contains receptacles for supplying current to equipment which cannot be conveniently plugged into the table receptacles. Then, too, an under-floor duct is provided in the large laboratory offices to which desk lamps and other electrical equipment may be attached.

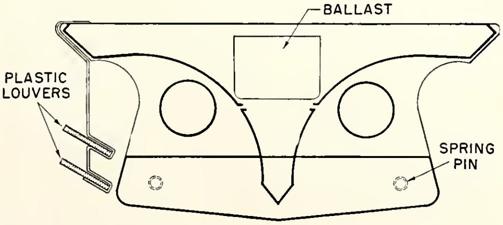
DC or other special current may be had in each laboratory by means of a pair of wires connected to a polarized receptacle in the wiring trough and to a plugboard in the nearest electric shaft. From the shaft plugboard, trunk lines lead to a master plugboard in the motor-generator room on the first floor. At present 115 and 230 volt DC is available, but through this system every laboratory can be supplied with any type of current of which a source is provided.

Laboratory Lighting. Exceptional progress in artificial light since the Mellon Institute was built has rendered the incandescent luminaires of 1936 obsolete. The advent of fluorescent lamps in 1938 and their rapid development during the war years has provided the means for improving laboratory seeing conditions. In the completion program, all laboratories, old and new, have been equipped with fluorescent fixtures. The existing structural arrangement of the building and the special seeing requirements of laboratory work limit somewhat the free use of available equipment. Considerable study was therefore devoted to the design of the new lighting arrangement.

Experience has demonstrated that much of the laboratory seeing task is in the vertical plane directly over the tables. It follows, therefore, that there must be adequate illumination in this plane as well as on the tables in the horizontal plane. Furthermore, since some apparatus extends above eye level, the illumination in the vertical plane should be good to within about a foot of the ceiling.

The two-window laboratories because of their size, 12 feet wide by 19 feet long by 10 feet high, afforded the greatest problem and so the relighting of these laboratories was attacked first. Structural difficulties and wiring costs confined the location of luminaires to surface mounting directly down the middle of the room. With these limitations, available industrial type luminaires were first tried. These types of units left the ceiling dark, placed most of the light in the center aisle where least required, and caused the laboratorian to work in his own shadow as he faced the table on either side. Commercial types of luminaires provided more light to the ceiling, but again the laboratorian was looking into his own shadow and the majority of light was directed into the center of the aisle.

Figure IV.44 Cross-section of fluorescent lighting fixture.



It became obvious after study, that it would be necessary to use a fluorescent tube with the highest lumen output per foot, which, at present, is the 5 foot 85-watt T-17 tube and that a fixture would have to be designed employing two of these tubes with a wide parabolic reflector behind them so located as to direct the major portion of the light toward the walls of the laboratory just above the laboratorian's head. These units would require only lengthwise shielding since viewing of the lamp from the side would not take place in the single laboratories. The construction of this luminaire is illustrated by a cross section view in figure IV.44.

Three samples of this type unit were made and installed in tandem down the center aisle of one of the single laboratories. Results were very gratifying. However, careful check of the footcandle values on the vertical plane made it apparent that the angle of the reflectors could be lowered to achieve even better results. Consequently, other samples were made in which the direction of the reflector was lowered 17°. Maximum results were then obtained and all of the two-window laboratories have been equipped with these lighting units. Using 4500° K lamps, the maintained lighting values produced on the horizontal plane at table level average 32.7 footcandles and in the vertical plane above the tables, 41 footcandles.

The adoption of these units in the double laboratories seemed desirable. Tests revealed that satisfactory lighting environment could be obtained by the use of five fixtures, two in tandem in each aisle and one perpendicular to the center table and at the end. Since the laboratorian standing facing the center table had full view of the lamp in the opposite fixture, it was found necessary to provide shielding of these inside lamps. There was no need to shield the lamps on the wall side of any of the fixtures nor was there any need to shield the fixture on the end of the center table, because these lamps were not in full view. The laboratorian would normally see this fixture in the fringe of vision and would be looking along the length of the lamp. To provide desirable shielding, it was only necessary to suspend two plastic venetian blind slats to cover the critical viewing angle. See figure IV.44. The maintained lighting values on the horizontal plane at tabletop average 44.5 footcandles and on the vertical plane above tabletop 69.6 footcandles, with 4500° K lamps.

Maintenance of this particular fluorescent fixture has been reduced to a minimum by confining the metal to steel, finished in white enamel and with provisions for readily removing the louvers for cleaning without disturbing the fixture. All electrical parts can be replaced without taking the fixture down. Experience has demonstrated that lighting with this equipment is entirely satisfactory.

In the narrow laboratory offices, the same type luminaire has been employed, except that 4 foot 40-watt fluorescent tubes are used. These units provide an average of 30 footcandles general illumination.

In the other offices a standard commercial type luminaire employing four 4 foot warm-tint fluorescent lamps has been used. These fixtures are only 5¼ inches in depth with a curved "Albolite" glass bottom panel and are surface mounted. A general level of 30 footcandles of illumination can be provided.

Laboratory desks in both the single and the double laboratories have been provided with local fluorescent lamps mounted so as to slide back and forth across the desk as desired and with an adjustable reflector to shield the lamp from view and direct the light where wanted. Intensities range from 50 footcandles to 200 footcandles.

Laboratory Furniture. Owing to the variety of the Institute's investigations and because the occupancy of the laboratory rooms changes from time to time as the researches expand or are replaced by new investigations, high flexibility of the laboratory equipment is of prime importance. A laboratory equipped for a study in organic chemistry can seldom be used for an investigation in, say, the field of ceramics without some change in the equipment, at least in the type of storage cabinets. While the walls are permanent, everything within the rooms is easily rearranged or removed entirely. The vertical wall T-slots afford flexibility in the shelving arrangement, as well as support for additional service pipes, instruments and apparatus it may be desirable to attach to the wall. Flexibility in the laboratory furniture has been accomplished by making the storage cabinets of uniform size so that they may be interchanged at will. The steel structure supporting the tabletops and forming the openings into which the cabinets fit is composed of standardized members most of which are used either in wall or center-type tables. The framing members are fitted firmly together without the use of bolts, screws or nuts; the only tool required for the assembly is a rubber mallet. The tabletop slabs are likewise in sections, the joints being made without splines, and the fume hoods are so constructed that they are easy to move around.

The steel framework of the laboratory tables consists of vertical supporting frames made of formed chanels and bottom and top horizontal or spacing frames. Riveted to the sides of the vertical frames are turned stainless-steel lugs or buttons that engage suitable slots in the horizontal frames.

The front edge of the upright frame above the level of the bottom spacer is finished with a formed pilaster that serves as a stop and division member between the removable storage cabinets. Near the top of the pilaster is welded a threaded stud to receive a clip and acorn nut for holding the storage cabinets in place. The space between the plane of the bottom spacer frame and the floor is closed by a steel sheet and aluminum cove-mold set back from the face of the cabinets to allow toe room. Clips instead of bolts are used for attaching the toe-space member to the vertical frames. On the back edge of the upright frames are two additional stainless-steel lugs for attaching sway braces or pipe hangers. The two legs of each frame are provided with screws to facilitate the leveling of the table frame structure. Identical vertical frames are employed for wall or center-type tables.

The bottom horizontal or spacer frames supporting the removable storage cabinets are constructed of formed angles welded at the corners and provided on the ends with slots to engage the lugs on the upright frames. Wall and center-type tables have the same bottom frames. The top horizontal spacer is also a four-sided angle frame with welded corners, the rear corners being reinforced with gusset plates. Provision is made on each end for engaging three lugs on the vertical frames. All spacer frames are of suitable length to make the center-to-center distance between uprights 40¾ inches. The top horizontal frames for wall tables, clamped to the wall by clips bolted to the wall T-slots, are wide enough to give a space of 6 inches for drain pipes, etc., between the back edge of the vertical frame and the wall. For center-type tables the top spacer frames are supported by two upright frames on each end, with an 8-inch space between the verticals for pipes. All the service pipes for center tables are carried below the tabletop on pipe hangers engaging the lugs on the back edge of the vertical frames. Sway braces may be hooked over the rear lugs on the uprights, but are rarely necessary because wall tables are clamped to partition walls and all tables are built out from a vertical frame attached to the wall at the window end of the room. Steel end panels, which are used on the free ends of the center tables and on shortened wall tables, are equipped with concealed slots which engage the lugs on the side of the vertical frame.

Lead-coated or "Bonderized" steel is used for all laboratory table framing members. Exposed surfaces of framing members are finished with baked acid-resisting aluminum paint, and the concealed parts with acid-resistant green paint.

Wood storage cabinets are used with a formed steel angle facing piece on each unit. The facing piece is finished with baked aluminum paint to match the exposed parts of the steel framing. The cabinets have flush fronts with concealed horizontal dividing rails and are made to such accuracy that any drawer of a given size will fit into the corresponding opening in any cabinet.

Cabinet fronts are made of 1-inch thick plywood, 7-ply, with a face of comb-grained Appalachian white oak. Cupboard doors, instead of having solid wood cores, have cores composed of cells about 1½ inches square, which makes for lightness and decreases the tendency to warp and twist. The ends, back, top and bottom of the cabinets are of plywood panel construction. Drawer pulls and cupboard knobs are metal-reinforced molded black plastic.

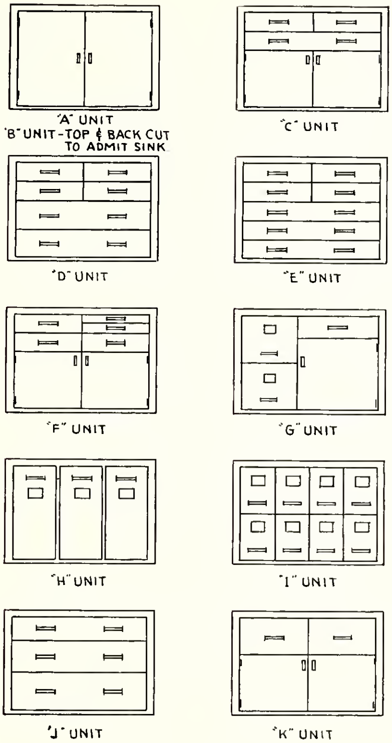


Figure IV.45 Storage cabinets.

Eleven types of standard size storage cabinets, consisting of various combinations of cupboards, drawers and bins, are available. The front elevation of these units is shown in figure IV.45. The smaller flat drawers are replaceable in any unit by a drawer divided into compartments for corks, etc., or by two shallow drawers for storage of pipettes, thermometers, etc., as shown in the F unit. In one special laboratory two of the removable units consist of steel rubbish boxes on casters which receive ceramic waste materials dropped into them through openings in the ¼ inch steel bench top. Special tongs, gripping suitable cutouts in the ends of the units, make the standard cabinets easy to handle. A specially designed four-wheel platform truck is provided for moving the units from laboratory to laboratory.

Laboratory Sinks and Tabletops. All laboratory sinks are made of a material developed at the Institute. This is a porous fired ceramic material having voids filled with a polymerized organic compound. Because of the low firing temperature, the sinks are straighter than those made of a vitrified body. After firing, but before impregnation, the ceramic body is easily worked, and it is thus possible to eliminate any depressions in the bottoms of the sinks so that they will drain perfectly.

Two types of sinks are used, one for mounting under the tabletop and the other for installation at the end of the center table. The first measures 12" by 18" by 6" deep, while the second, which has integral double drain boards, is 52" by 20" over-all and includes a basin 24" by 18" by 8½". Cup sinks, formed by extending a vertical branch of the drain pipe from the horizontal line up to a hole counterbored on the underside of the tabletop, are used instead of troughs for condenser discharge, etc.

Tabletops are "Alberene" stone, regular grade, 1½ inches thick, 30 inches wide for the wall tables, and 56 inches wide for the center tables. In some special laboratories, wood, stainless steel and ¼ inch steel plate tops are used.

Shelving and Shelf Brackets. By use of the adjustable shelving devised by the Institute's engineers, the distance between shelves may be varied in intervals of 1¼ inches. Additional shelves may be installed or the shelves may be easily removed to give wall space for instruments or to make room for bulky apparatus, such as large ovens or conditioning cabinets, on the tabletops.

The shelf brackets are of aluminum, cast in a permanent mold, and thus require no fitting. They are installed in the T-slots by placing the bracket on its side, permitting a T-lug near the top of the bracket to enter the slot, turning the bracket upright, and finally engaging a pin on the lower part of the bracket in one of the holes in the back of the T-slot. The pin is notched to hook over the back wall of the T-slot, so that the bracket cannot be dislodged by an accidental upward bump on its outer end. Die-cast shelf brackets are made for shelves both 7 and 12 inches wide, some with and some without a shelf-dividing member, so that, where desirable, shelves may overhang the last bracket and extend to the end wall of the room. The brackets for the lower shelves, which are installed directly over the wiring troughs, are of the inverted type, so that these shelves will be as low as possible. Sand-cast brackets for shelves 18 inches wide are used for analytical balance shelves on the corridor end of the large laboratories and for animal cages in some research rooms.

The shelves in the original installation are impregnated "Transite" finished with an acid-resisting high-gloss lacquer, but many wood shelves similarly finished have since been added. It has been found that the "Transite" shelves have a tendency to sag if heavily loaded. This sagging can be overcome by occasionally turning the shelves.

Although shelves are not always desired on the center-type laboratory tables, suitable cast-aluminum shelf supports are available. The supports are bolted to the tabletops, and, as they carry no service pipes, may be erected and taken down at will. This arrange-

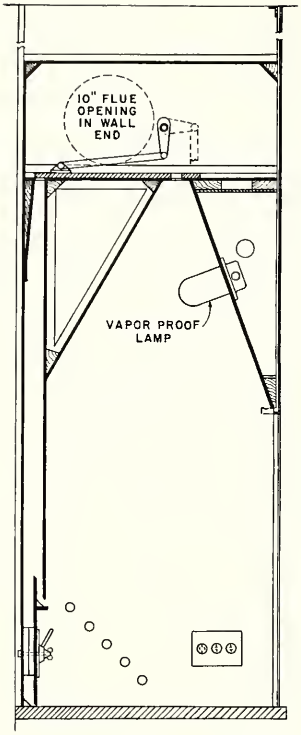


Figure IV.46 Section through fume hood.

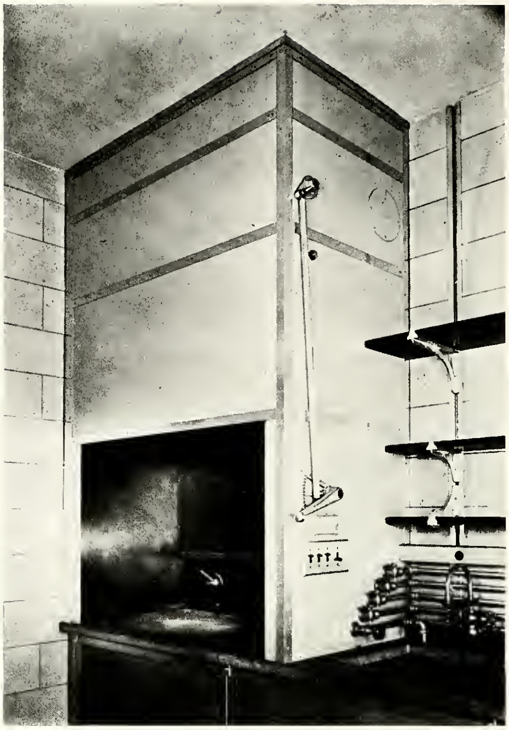


Figure IV.47 Fume hood.

ment provides two shelves, one 9 inches wide, 15 inches above the tabletop, and one 7 inches wide, 9¾ inches higher (figure IV.39). A lip is provided at each edge of the impregnated "Transite" shelves to prevent bottles from being pushed off.

Fume Hoods. Much attention was given to fume hoods and several different hoods were built and tested before a suitable design was decided upon. The original hoods were designed to operate on 400 cubic feet of air/minute but this was later increased to 600 cubic feet (face velocity, 55 feet/minute).

The hoods adopted are of the open-front type, 54 inches long, 30 inches deep, with a clear opening in front 33 inches high. An inside height of 60 inches is provided for setting up tall apparatus and the floor of the hood is the standard laboratory tabletop. "Transite" board is used for the construction of the hoods, the inner surfaces which come in contact with the fumes being impregnated, and the exterior finished with "Vinylite" paint, as on the removable panels at the window end of the room. Aluminum moldings are used for trim. A cross section of the hoods is shown in figure IV.46 and an exterior view in figure IV.47.

In addition to the usual draft slots at the top and floor of the hoods, an auxiliary slot about 12 inches (on later equipment this has been increased to 18 inches) from the bottom contributes considerably to successful operation. Most gases are evolved a distance above the floor of the hood and the pull from this slot prevents these fumes from straying out of the hood. This auxiliary slot is adjustable by raising or lowering the panel beneath by means of eccentrics. Adjustment of the hood for handling light or heavy gases is made by an arrangement of slide valves in the plenum chamber, operated by a lever on the end of the hood. It is possible to apply all the draft to the top of the hood or to the bottom, to proportion it between the two in any desired ratio, or to close the draft off entirely. In the end of the plenum chamber opposite the flue is a capped opening to which may be connected a canopy installed over apparatus in the room from which it is desired to carry off fumes. The hood draft should be completely closed at such a time.

Outlets for services in the hood are all on the end opposite the flue and consist of cold water, air, gas, vacuum, steam and AC electricity. Cocks for controlling the plumbing services and electric switches are outside the hood. Switches are provided for the light in the hood and for the fan motor in the attic. A cup sink for condenser discharge is located in the floor of the hood. Neon pilot lights, indicating the position of the fan motor control switch, are installed on the end of the hood and in the pull-box over the laboratory entrance door in the corridor. It is the watchman's duty on his first round at night to turn off any fans which may be running (as indicated by the pilot light in the corridor), unless a note has been placed in the label holder on the hood that the fan was intentionally left on. As a rule, each fan in the attic supplies draft for four hoods—one on each laboratory floor—but the fan will continue to run as long as any control switch is in the "on" position. Each hood is provided with a separate flue to the attic, where the four flues served by one fan are connected to a manifold constructed of steel protected with an asphalt coating. Equalization of draft to the four flues is made by dampers in the manifold. The chemical stoneware hood flue elbow projects into the laboratory about 1½ inches and is sealed by calking compound into the opening in the end of the hood plenum chamber. As there is no duct work directly connected to the hood, the installation of a hood in or the removal from a laboratory is simplified. Suitable couplings are provided in the service piping, so that a hood can be readily disconnected.

Laboratory Desks. Although the special laboratory desks (figure IV.40) were designed particularly for the small laboratories, they are also used in the offices of the large laboratories.

Their length is 43 inches, width 30 inches, and the top overhangs 5 inches at the back to clear the service pipes and drain serving the adjacent chemical table in the small laboratories. While the single pedestal (left-hand side) of the desk includes no vertical letter-filing space, this may be had in the small laboratories by using a G unit in the first section of the chemical table. This unit contains two such drawers as well as a card file drawer and a stationery cupboard. Above the working surface of the desk is a bookcase section with sliding plate-glass doors and adjustable shelves.

Features of the desk are a light on a flexible arm, later replaced with a fluorescent fixture, a receptacle for connecting a microscope lamp, a sliding shelf with glass insert for reference tables, a convenience tray in the kneespace drawer, a drawing board sliding in guides on the end of the desk, and removable card file sections to fit in the book case. The desk wiring is between receptacles on each end of the bookcase section, so that in the large laboratory offices two desks may be connected with a short cord and supplied with electricity from one outlet in the underfloor duct. No provision for the telephone is necessary, except a bushed hole in the desk top, as the instrument has the ringer box in the base. Telephone lines are brought to each laboratory and laboratory office through an underfloor duct system. The desk and bookcase unit is constructed of steel with a baked aluminum finish and a working surface of brown linoleum.

SPECIAL LABORATORIES

A number of constant-temperature-humidity rooms are included in the Mellon Institute's facilities. One such room, about 220 square feet in area, is equipped for testing paper and textiles. A temperature of 70± 2°F, and a relative humidity of 65± 2% is maintained. The completion project has included two similar rooms, one of which is provided with a hood for exhausting fumes from lacquer films which must be dried under controlled conditions. This hood operates on the air normally exhausted from the room to compensate for the fresh air admitted to the system.

There are also two smaller air-conditioned rooms for general use, in which the temperature can be varied from about 40° to 120° F, and the relative humidity from 20 to 70%. The temperature in these rooms can be controlled to within ±0.50° F, and the humidity to within ±1% or less. All controlled-condition rooms are insulated with cork or "Fiberglas", the paper and textile laboratory and similar rooms having walls of terra cotta and the others of plaster. Wall T-slots are also available. The conditioning is accomplished by means of standard York conditioning units with forced air circulation over (1) water or brine spray cooled to approximately the dew point corresponding to the relative humidity desired, (2) a dephlegmator to remove droplets, and (3) a steam coil for re-heating the air to the desired room temperature and controlling that temperature. Steam valves are operated by controls, which start, stop and select the speed of the compressor, and by-pass dampers are operated by air pressure from Johnson Service Company thermostats and humidistats.

In another air-conditioned room a temperature of 75° F and a relative humidity of 65% are maintained. Such studies as the measurement of volume changes in cements and the effects of high humidity in the storage of commodities are carried on here.

On the second floor are several air-conditioned rooms used as spectroscopic, mass-spectrographic and x-ray diffraction laboratories. There is also a laboratory for petroleum wax investigations that includes constant-temperature rooms for 90°, 70° and 40°F.

A furnace room 25'0" by 135'0" located on the eighth floor is used largely in connection with ceramic researches. Special features of this room include a firebrick floor, insulating firebrick flues, thermocouple conduits between central panel locations and openings in the walls, columns and floor, and also a fresh-air supply system. The room is two stories high, there being no attic over this section of the building. The equipment in the furnace room consists of kilns of various sizes, load test and panel spalling test furnaces for refractory brick, and pot furnaces for fusion tests and crucible heating. All these furnaces are fired with natural gas.

On the second floor of the building is a suite of five rooms designed for heat-insulation research, comprising a conductometer room, control room, general laboratory, sample preparation room and office. The conductometer room, in which all the conductivity tests are made, is an inside room with no windows and is thus not subject to rapid changes in temperature. It adjoins the control room, to which it is connected by a system of conduits, so that the regulation of the power input to the conductometers and the recording of temperature and power data are all done in the control room. By means of a constant-voltage regulator and two tapped transformers a regulated voltage of from 2 to 200 volts is available.

Also located on the second floor is an electric furnace room for general use in which are a Hoskins muffle furnace, a 26 kw Hoskins heat-treating furnace, a 35 kw high-frequency induction furnace and other special furnaces. The Hoskins furnaces have Hoskins temperature controllers.

About 10,000 square feet of floor space on the first floor is used as a unit-plant development laboratory. Most of this space is two stories in height and is served by 5-ton electric traveling cranes. Round stoneware flues, 10 inches in diameter, and rectangular flues, 18 by 10 inches, carry off fumes and noxious gases. In addition to the regular services, 175-pound steam and 125-pound air pressures are available on this floor. By means of a hatchway and monorail crane in the receiving department on the third floor, heavy and bulky equipment can be lowered directly to the unit-plant laboratory. Electric service is provided by underfloor ducts as well as by receptacles in the walls.

A considerable part of the first floor is devoted to the chemical engineering laboratory. Here are set up, ready for use at all times, hydraulic presses, physical testing machines, dryers, centrifuges, etc. Grinding and pulverizing equipment is housed in a separate room, where provision is made for carrying off dust through the vent flues.

AUDITORIUM, CONFERENCE, LOUNGE AND OFFICE ROOMS

The auditorium contains 350 comfortable fixed opera chairs. Sixteen-mm sound motion pictures and large and small slides are projected from a booth over the entrance. The stage is equipped for chemical demonstrations and an amplifying system is provided. The room is used for the regular meetings of many of the scientific and technical organizations of the district. A number of national conventions are also held here. This room is air conditioned.

Opening from the third floor lobby, which is used for auditorium meetings, is a large well furnished room for conferences, round-table discussions and similar purposes. It is also used for social affairs of Institute members and for this purpose is adjoined by a small kitchen for preparing light refreshments. A similar room, which can be divided into two parts for other conferences, is available as is also a small conference room seating about 50.

There is provided in the program special quarters for the Mellon Institute members' organization, the Robert Kennedy Duncan Club. This suite includes lounge, game, and office rooms.

SAFETY FEATURES

At frequent intervals on the ceilings of the corridors on all laboratory floors are placed fire-blanket boxes. These (figure IV.41) are V-shaped metal containers, hinged to a frame attached to the ceiling and held in the closed position by a latch with a pull chain. Rolled up in the boxes are blankets tied to the frame by light cords about 2 feet long. When the latch chain is pulled, the blanket falls out and hangs in a position where a worker, who has accidentally had burning liquid spilled on his clothes, may wrap the blanket around himself and extinguish the flames. If it is necessary to take the blanket into a laboratory, the cords attaching it to the ceiling frame may be easily broken. These blankets have been used in the Mellon Institute for over 15 years and have on several occasions demonstrated their effectiveness. Shower sprays can be readily installed, if desired, as the water pipe is over the tabletop, where a connection can be made. Recessed into the walls in all laboratory floor corridors are first-aid cabinets in which are kept the usual tape, bandages, antiseptics and burn remedies.

Fire-extinguisher niches (figure IV.41) are built into the terra cotta corridor walls in numerous places. On the laboratory floors 10-pound carbon dioxide extinguishers and gas masks are placed in these niches, and 2½ gallon foam extinguishers are used on the lower floors. Forty-gallon foam and 100-pound carbon dioxide extinguishers are located in the unit-plant section. No provision is made for combating fires with water; chemical extinguishers are much more effective in laboratories.

MECHANICAL EQUIPMENT FOR LABORATORY SERVICES

Compressed air at 45 psi pressure is supplied to the laboratories by two Ingersoll-Rand compressors—one class ES-1, 10" by 9", and one class ER-1, 10" by 8". For a limited supply of air at night a smaller compressor (class ER-1, 6" by 4") is used. One-hundred psi air pressure for sand blasting and other special purposes is furnished by another compressor (class ER-1, 7" by 6"). The thermostats controlling the heating of the building are operated by compressed air from two Gardner-Denver compressors. As the operation of the air-conditioned rooms is dependent upon the maintenance of thermostat air pressure, an alarm is arranged to ring if the pressure falls, owing to tripping of a breaker or other cause. All the air compressors have V-belt drives. The Ingersoll-Rand compressors run continuously, the air pressure being regulated by closing the intake valves when air is not required. Cooling water is circulated through the cylinder jackets only when the air is being compressed.

Two size H-4 and one size H-6 Nash "Hytor" vacuum pumps provide a vacuum of from 22 to 25 inches of mercury. The pump bodies are made of nickel-iron to withstand the effects of erosion and possible corrosion.

There is a large receiver in the system permitting the pumps to operate intermittently.

Other building service mechanical equipment includes an 8-ton York refrigerating machine, using ammonia, for making ice and cooling two storage rooms, a York "Freon" machine for cooling drinking water, a 20-horsepower Spencer vacuum cleaner, a 1000-gallon steamheated water heater, and an incinerator.

The building is heated by steam received from street-lines at 175 psi pressure. The heating steam, after being reduced in pressure, is piped to the attic, from where it is fed downward by gravity to the radiators. Johnson Service Company's dual thermostats are used. With this system, the temperature in the building is reduced to 55° F during nonworking hours, but any room may be brought up to daytime temperature by pressing a button on the room thermostat.

The elevator installation consists of two automatic push-button type Westinghouse passenger elevators having a speed of 500 feet/minute, an automatic service elevator, and an 8000-pound freight elevator. All elevators are automatically leveled with the landing, and on the passenger and service cars the operation of the doors is controlled by photoelectric cells. The motor-generator sets for the elevators shut down automatically if the cars are not used for a predetermined period of time and start up again when a floor button is pushed. A special electric lift near the freight elevator operates between the eighth floor and the attic since none of the elevators reach the attic (to make them do so would require penthouses on the roof, which could not be tolerated on a classical type of building). Three electric dumbwaiters with full automatic control are used. Two operate between the third and sixth floors—one between the receiving department and the main stock room, and the other between the auxiliary stock room and the main stock room. The dumbwaiters also serve the three levels of the library stack room, the shaft openings on these floors being at floor level so that book trucks can be rolled into the dumbwaiter cars. The third dumbwaiter operates between the third floor, where the receiving entrance is located, and the post-office on the fourth floor, thus obviating the necessity of trucking mail on the main floor.

SERVICE DEPARTMENTS

In the main stock room, located on a mid-laboratory floor, the sixth, is maintained a large supply of chemicals, laboratory apparatus, and sundries for laboratory, office and maintenance. The equipment consists mostly of standard steel shelving, although special provisions have been made for storing glass tubing and rod, corks and stoppers, glass condensers and other equipment. The stock is dispensed over counters in which are built glass showcases for displaying new items. Stock room records are kept by a "Kardex" system, which includes perpetual inventory and purchase record cards.

On the third floor, next to the receiving department, is an auxiliary stock room which handles hardware, pipe and fittings, bar and sheet steel, lumber and other materials used in the unit plants and shops and for maintenance. It also serves as a tool room for the adjoining shop reserved for the use of research workers. Here they may repair or construct apparatus and not interfere with the mechanics in the main shop. The equipment includes a work bench, power hack saw, metal turning lathe, drill presses, grinder and wood-working saw.

The main mechanical facilities comprise completely equipped machine, sheet metal, pipe, wood-working, paint, and electrical shops, all having skilled men. Special apparatus and mechanical equipment for various researches are constructed in these shops.

The apparatus department stocks, calibrates and keeps in good working order Institute-owned laboratory-scale physical apparatus and testing and processing equipment. It also maintains an instrument shop.

The printing and duplicating shop has a small printing press, mimeograph, multilith duplicator, addressograph, paper cutter, and equipment for punching and stitching. Reports and other manuscripts requiring more copies than can be made with carbon paper are duplicated here from typed stencils or lithographic plates. Reports are stitched, bound in printed covers and trimmed; and special forms are produced.

In the analytical and physical measurement departments, data is secured for research workers, relieving them of tasks for which their laboratories may not be well equipped and allowing them to devote their time to more important phases of their investigations.

The chemical physics department carries out both routine measurements and fundamental studies for the research projects with its complete facilities for x-ray diffraction, and for emission, infrared, Raman and ultraviolet spectroscopy.

There is also a glass-blowing shop, a photographic and drafting department, a laboratory glassware wash-room, and a laundry.

The staffs of several of the larger research projects include secretarial assistants, but most of the stenographic and typing work for the members is done in the general office. A vault for filing technical reports is fitted with special steel equipment, which includes flat steel boxes from which the reports may be removed by pulling the box half-way out of its place, allowing the hinged front to drop after the hinged half-top has been raised.

The library, recently air conditioned, has been described in the literature. In comfortable surroundings members of the organization have access to books and journals pertinent to their work, specialized bibliographic service being extended by the library staff. The library has been built up soundly around general reference, specific department and fellowship needs, and contains essential treatises on chemistry and allied sciences. It is being expanded constantly to keep abreast of research progress throughout the world and to meet the requirements of the Mellon Institute's membership.

7

UNITED STATES DEPARTMENT OF AGRICULTURE, REGIONAL RESEARCH LABORATORIES

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Four Regional Research Laboratories are operated by the Bureau of Agricultural and Industrial Chemistry of the United States Department of Agriculture. The Northern is at Peoria, Illinois; the Southern at New Orleans, Louisiana; the Eastern at Wyndmoor (Philadelphia), Pennsylvania; and the Western at Albany, California. The program of research for these laboratories is directed toward the discovery and development of new and wider uses, and extended markets, for agricultural commodities and their products and by-products.

BUILDINGS

The main building of each Regional Research Laboratory is a U-shaped structure of three stories and basement. It is divided into an Administrative Unit forming the front or base of the U, a Chemical Laboratory wing for the research laboratories, and an Industrial Laboratory (Pilot Plant) wing primarily for semiplant-scale process development (see figure IV.48). There is an attic over the Chemical Laboratory wing and Administrative Unit and that part of the Industrial Laboratory wing devoted to laboratories.

The buildings are of reinforced concrete-frame construction except for the part of the Industrial Laboratory Wing devoted to process development, which is framed of structural steel. The floor system is beam and slab design which was poured in smooth forms, making furred or plastered ceilings unnecessary.

The air-conditioned laboratories are provided with double sash, the outer sash being of steel (projected type) and the inner sash of wood (single sash with storm-sash hangings). At all laboratories the outer sash are glazed with heat-absorbing glass on the sun exposures. The windows in the Industrial Laboratory wing are glazed with ⅛-inch ribbed glass. In some instances, due to excessive glare, it has been necessary to replace this ribbed glass with clear glass. A maximum number of windows have been provided in all three units of the building.

BUILDING SERVICES

The first, second, and third floors of both the Chemical Laboratory wing and Administrative Unit, except in the Western Regional Research Laboratory at Albany, California are air conditioned with year-round control. At the Western Laboratory, room-ventilating (without cooling) units that draw fresh air from beneath the windows are provided in each bay.

Throughout the Chemical Laboratory wing and the standard laboratories in the Industrial Laboratory wing, the services are carried to the various rooms by drop risers in shafts lining both sides of the corridor. These shafts are so arranged that, in addition to the vertical pipe lines, installed laterals may be run from shaft to shaft through furred enclosures over the entrances to the laboratories. These shafts also contain air ducts for conditioned air, waste air ducts to hoods, and vent stacks from hoods. Services are accessible by doors in corridors. This use of laterals is not recommended where risers can be used.

Both wings are supplied with the following services:

A. Cold water at approximately 35 psi static pressure at third-floor level.
B. Compressed air at 60-100 psi.
C. Gas—local utility.
D. Electricity—three-phase—four-wire system, 120 and 208 volts, 60 cycle, supplied from three 1000 K.V.A. transformers.

Process steam at nominally 15 psi is supplied to the Chemical Laboratory wing and at 125 psi to the Industrial Laboratory wing by steam generators in a separate service building.

Vacuum service is suppled to the Chemical Laboratory wing from a two stage steam-ejector pump with barometric condenser to provide a vacuum of nominally one inch of mercury absolute pressure.

Recirculating hot water at 150° F is provided for the Chemical Laboratory wing and Administrative Unit. Storage tank has a 1050 gallon capacity and can heat 500 gallons per hour.

Distilled water is piped by gravity to all laboratories. The still, storage tank and distributing system are lined with block tin. Storage tank has capacity of 500 gallons. Two 25 gallon per hour stills provide an ample supply.

Passenger and freight elevators are located at the turn of the corridor in the Administrative Unit near the Chemical Laboratory wing. An electric dumb-waiter across the corridor from the freight elevator serves the library on the first floor, and is open to the corridor at all floors.

The following shops are located in the basement of the Administrative Unit and in the adjacent end of the Industrial Laboratory wing: woodworking, plumbing, machine, instrument, sheet metal, electrical and paint.

In the basement of the Chemical Laboratory wing provision is made for physical testing, constant-temperature, and cold storage rooms to be used for certain temperatures desired at each laboratory.

ADMINISTRATIVE UNIT

This unit houses, in the basement level, the chemical and mechanical stores and receiving room and includes most of the service shops, as well as air-conditioning units and some building services. Most of the unit, however, is devoted to division and administrative offices. In addition to these offices, a library and emergency room are on the first floor, and an assembly room, a glassblowing shop and rooms for photography, photostating, and blueprinting are on the third floor except at the Southern Regional Research Laboratory where the glassblowing shop has been located in the basement.

CHEMICAL LABORATORY WING

Three floors of standard laboratories are located in this wing. The plan is based on a unit of three 16'0" by 24'0" rooms; the two outer rooms are standard laboratories with complete facilities; the center room is divided by removable partitions into two office studies and a utility room, and without the partitions, is a potential laboratory. Figure IV.48 illustrates the arrangement. The utility room may be devoted to any special use, such as constant-temperature room, special-equipment room, or dark room. The basement of the Chemical Laboratory wing has, in addition to air-conditioning units and transformer vault, a receiving room, and provision for future cold-storage rooms, and other special rooms, such as for sample storage and sample preparation. Effort was made to eliminate heavy processing equipment from this wing in order to prevent vibration of the building. The refrigeration machinery is mounted on isolated footings with special dampening mountings. The Chemical Laboratory wing has been arranged to allow the work requiring greatest freedom from vibration to be located on the first floor.

LABORATORY ROOM SERVICES AND EQUIPMENT

The standard research laboratory is planned to provide working space for two chemists with office-study adjacent. The equipment of two standard laboratories is outlined in figure IV.48. Because the selection of construction materials for laboratory furnishing was determined by the degree of economy necessary, as well as by the nature of the work, and because under particular limitations different selections were still possible, no special attempt has been made to identify such materials in the following descriptions.

The wall and center tables are made up of standard-size sections and interchangeable end members, with all cabinet inserts interchangeable except at the dump sinks. There are usually three styles of interchangeable inserts. The tabletops and reagent shelves are spliced at section lines. Each table section is 41 inches long between end-frame centers and all tables are assembled in multiples of 41 inches. The reagent shelf is directly above the turret and service outlets at the rear of the working surface. Each table section carries a full complement of services arranged in the following order: cold water over a cup sink, compressed air, single-phase AC electricity, vacuum and gas. The air service, located next to the cup sink, provides for substitution of steam if desired. Air, gas and vacuum services terminate in heavy-duty plug cocks with long handles. All services are identified by color. Only cold water is provided at the dump sinks, with three outlets, two of which are suitable for aspirator pumps. Reagent cabinets with sliding glass doors are provided on the reagent shelf over the wall table in some of the laboratories.

The fume hood is designed to operate in air-conditioned laboratories with provision for sweeping the hood in closed operation without waste of room atmosphere. The working surface is of heavy soapstone without built-in steam bath. The structure is of acid-resistant material enclosed by vertical panels reaching to the ceiling. In closed operation waste air from the air-conditioning system is provided under slight pressure and delivered to the hood chamber through slots in column ducts at either side of the hood sash. This air supply is turned on or off automatically through the opening and closing of the hood sash. The chemist is only responsible for the operation of the control damper in the exhaust line, as it is sometimes necessary to reduce the air flow for closed operation. Outlets for piped services are located inside of the hood in the back board below the lower fume slot. These services are controlled through needle valves with replaceable plugs and seats and remote control handles on the apron of the hood. Steam and water outlets are located to dip or discharge directly into a cup sink. All electric services and controls are in a flush plate in the apron of the hood. Except for service tip connections no metal is exposed within the chamber. The hood light is located in the top behind a glass panel and directed downward on the working surface. The base of this hood usually encloses cupboards, but in some cases, a steam drying cabinet. Each hood is served by an individual exhaust fan located in the penthouse.

Apparatus or chemical storage cabinets at walls are in units 4 feet wide with open recessed shelf at table level and sliding-door cupboards above and below. The doors of the upper sections are of glass.

No locks are provided on cabinets or cupboards except on one style of combination drawer-and-cupboard insert in the tables, one of which is assigned to each chemist and independently keyed.

The wash sink is of soapstone with all corners rounded and with integral drain board and box back. A peg board of moisture-resistant material extends the length of the sink. The height is such that persons of average stature can reach the top pegs. The services consist of a fixed-gooseneck mixing faucet and another gooseneck faucet for distilled water. Both faucets allow direct filling of 5-gallon stock bottles. Special sink mats prevent undue breakage of glassware. A safety shower with self-closing chain-operated valve is located above the end of the sink next to the doorway with the shower head directed obliquely downward.

A special cabinet is provided for storage and transfer of strong acids. This cabinet is of wood or fiber with acid-resistant finish. Tellurium-lead-covered top and shelves carry beaded edges or splash boards. The assembly is accomplished without metal pinning.

A 4-foot balance table with soapstone top is located in the office study. The table has a drawer and a draw leaf and is large enough for an analytical balance in a dust case and for a desiccator.

Above the single-pedestal desks in the office-study of most of the laboratories are special bookcase sections which furnish both book space and desk light without reducing the desk-top space. Other items of furnishings in the office-studies are shown in figure IV.48.

The laboratories are provided with small carbon-dioxide fire extinguishers at the doorways to the studies and to the corridors. Larger carbon-dioxide extinguishers are located in the corridors.

Artificial illumination of the laboratories is by semi-indirect lighting to provide 15 foot candles on all working surfaces. In some instances fluorescent light fixtures have displaced most of the semi-direct features.

An individual electric panel in the wall of the pipe shaft on one side of the vestibule carries nine circuits to each laboratory. Sufficient power is available to supply 6 kw to every laboratory room simultaneously. The conduit permits drawing wires to furnish 18 kw at any one laboratory.

The partitions dividing the laboratory rooms are either of tile or painted plaster on metal studding and lath. The floors are covered with linoleum. The laboratory color scheme largely comprises tones of green; no lead or iron pigments which might react to produce discolored walls and ceilings have been used.

Along the dividing partitions below the air-conditioning grille frames, a special heavy-gauge steel molding with projected vertical slot is mounted, locked to the partition, and plastered in. The molding is capable of supporting fairly heavy loads in the form of shelves or cupboards.

To provide safety exits, doors between laboratories and laboratory studies are without locks or latches. Doors from laboratories to corridor are also without latches, although provision is made for key and turn lock. These doors open inward with push-plate on corridor side and pull-handle within room.

All piped services are carried from shafts to tables in laterals a few inches beneath the ceiling of the room below and up through sleeves into the tables. There are no risers in the laboratory room except those for heating steam and condensate, which are located at the outer wall columns. Plugged tees are provided in service lines for any future extensions.

The obvious impossibility of foreseeing specific future needs in any research laboratory made it necessary to provide as much as possible in the way of general flexibility and convenience. Although the Department of Agriculture previously had much experience in laboratory construction; every effort was made to obtain further details concerning laboratory construction from others by visits to laboratories, by correspondence, or by conference. Some features within these new laboratories are innovations, which may, in turn, repay others for the valuable help they have supplied.

There are a number of special items of built-in laboratory equipment and furniture, but details concerning them would be out of place in this brief description of the Regional Research Laboratories.

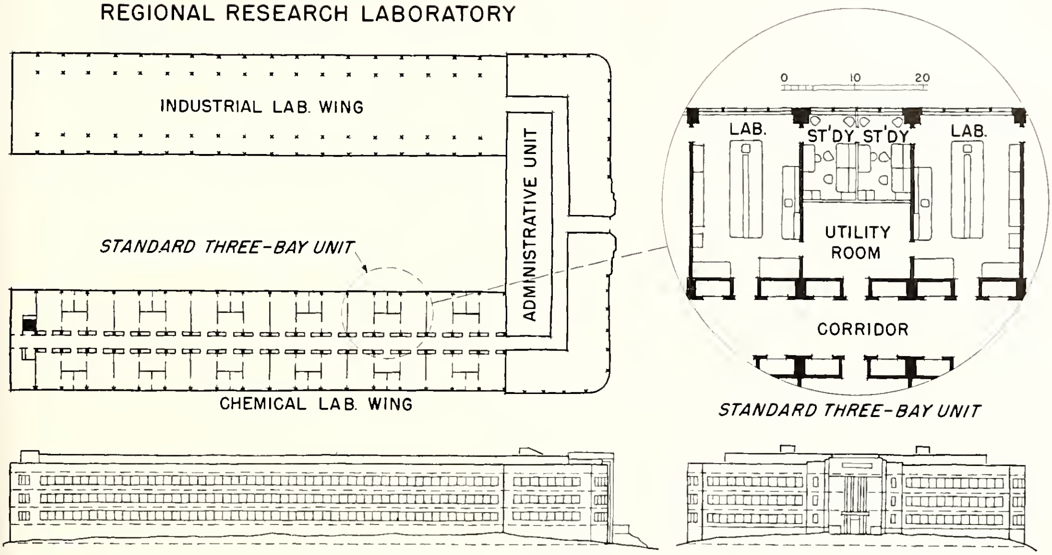


Figure IV.48 Regional Research Laboratory.

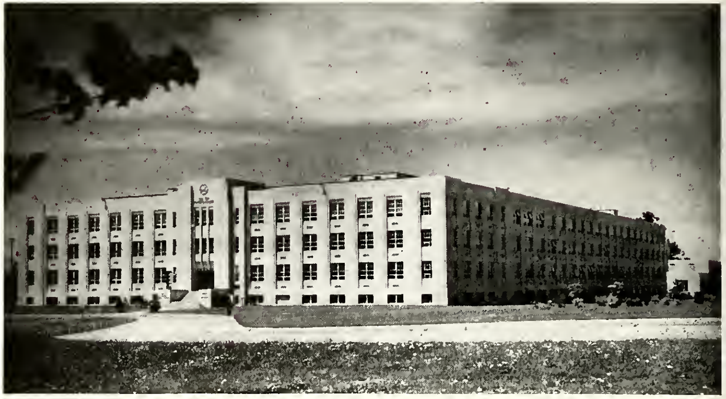
INDUSTRIAL LABORATORY (PILOT PLANT) WING

This wing, except the small part devoted to standard laboratories or other occupancies, is of steel-frame construction with free-standing columns along both sides of the wing running up to frame a monitor overhead. The columns are connected to the outer wall structure at the second floor level with permanent steel members which support a balcony floor along each side of the building. Alternate sections of these balconies are bolted instead of riveted and may be raised or lowered to any desired level. The piped services are carried in a U along the inner face of the columns near the second-floor level. Electric power of 2000 amps is supplied from a box-bus conduit circling the wing at the outer wall near the first floor level. The entire area available for process development is amply provided with floor drains and special plugged drain connections. Part of the ground floor level is occupied by service shops. The deck over these shops is constructed heavily enough to serve as additional Industrial Laboratory floor space. Floors and balconies are designed to carry a load of 500 pounds/square foot. Provision is made for additional working levels by framing with unit steel. With the exception of the Southern Regional Research Laboratory at New Orleans, a few standard laboratories are provided at three levels in the Industrial Laboratory wing next to the Administrative Unit, for the purpose of housing control and research work directly associated with process development.

The first six bays of the Industrial Laboratory wing at the Southern Regional Research Laboratory adjacent to the Administrative Unit are occupied by a Cotton Textile Mill on the first, second, and third floors and shops on the basement floor.

The arrangement of the Industrial Laboratory wings together with the experience encountered after some eight years of operations are described in detail on page 2014 of the November, 1948 issue of *Industrial and Engineering Chemistry*. The accompanying illustrations show the arrangement of some of the pilot plant areas at the four Regional Research Laboratories.

Figure IV.49 Western Regional Laboratory, Albany, California.



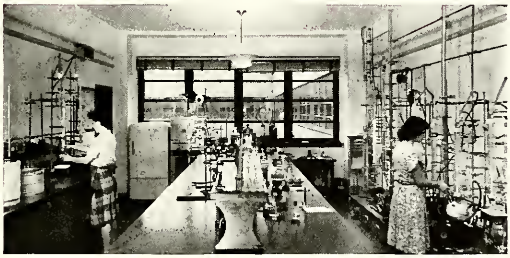
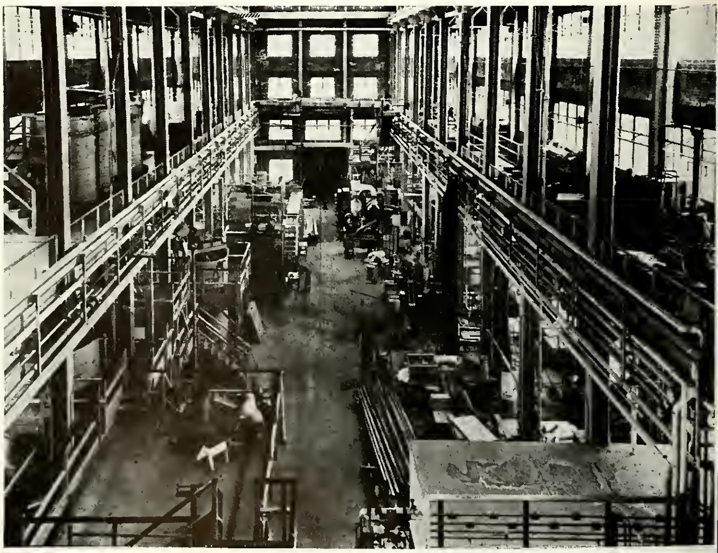


Figure IV.50 Organic research laboratory, milk products utilization investigations, Eastern Regional Research Laboratory.

Figure IV.51 General view of the pilot plant area, Eastern Regional Research Laboratory.



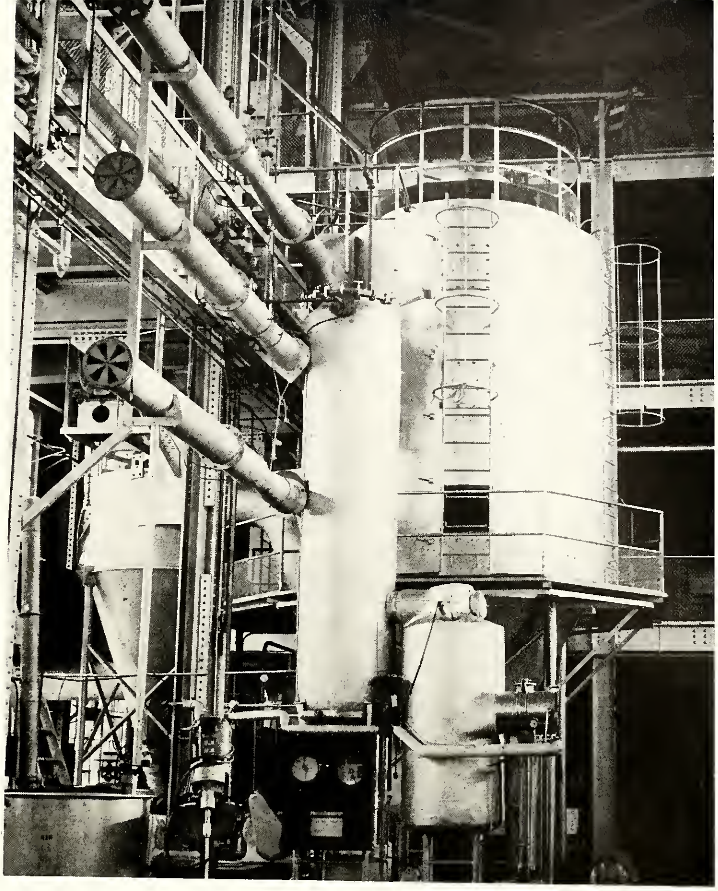


Figure IV.52 Experimental spray drier, Western Laboratory.

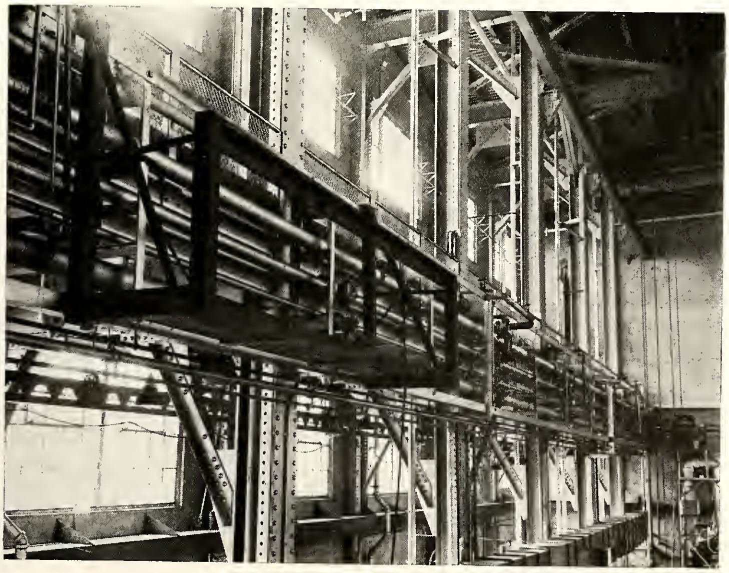


Figure IV.53 Arrangement of main utility service lines in pilot plant area.

8

BELL TELEPHONE LABORATORIES

Charles S. Haines[*]

Voorhees, Walker, Foley & Smith, New York, New York

The research facilities of Bell Telephone Laboratories, Murray Hill, New Jersey, designed by Voorhees, Walker, Foley & Smith, were occupied late in 1941. After the war, the original building program was increased and now nearly a half-million square feet of net space is provided for the purpose of research in the field of communications (see figure IV.54).

In the center at the link between the two main buildings is the main employee entrance and bus terminal. The Specialties building, just to the rear of the main structure, provides high ceiling space which can be used for testing and other purposes. The building at the extreme right is an acoustical laboratory, consisting of a "listening" room or auditorium, reverberation chambers, a large "dead" room and some standard laboratory space.

The visitor's entrance is at the right of the entrance forecourt. The other buildings are gatehouses, garage facilities and the heating plant. Two large dining areas are provided. The first and second floors of the forward left structure house the main dining facilities.

The principal right hand structure consists of three stories, attic and basement, while the building on the left is five and four stories, attic and basement.

The main building is an assembly of "T" and cross units, consisting of either one or two office wings, connected to twenty-eight modules of technical space.

This chapter will be devoted to the design of one of these typical modules of the laboratory area as follows:

A. The meaning of the module
B. The problem
C. Types of space
D. Dimensional considerations
E. Architectural considerations
F. Mechanical considerations
G. Electrical considerations
H. Structural considerations
I. Description of the module as designed

THE MEANING OF THE MODULE

The word "module" requires a definition. It is the smallest repetitive unit of space and must be complete in its repetition of the characteristics that enclose and serve this space. The characteristics of this repetitive element are its three dimensions, its architectural, mechanical, electrical and structural features and the services that may be added for the convenience of its occupant. Permanent features include the floor, the ceiling, the exterior wall and the corridor wall as well as heating, ventilation, and illumination by both natural and artificial means. The services that may be added for the convenience of the worker are water, drain, gases, steam, laboratory power, hood connections and subdividing partitions. In particular, this discussion is devoted to laboratory space, that is, the housing of the scientist and supporting workers in the complex modern industrial research laboratory.

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[*] Haines has discussed "Planning the Scientific Laboratory" in general in Architectural Record 108, No. 1, 107-124 (1950). This article is followed by descriptions of the General Electric (Knolls) and Corn Products laboratories.

THE PROBLEM

At the time the design was started for Bell Telephone Laboratories in Murray Hill, New Jersey, the organization was housed in converted factory space in New York City. For years there had been many difficulties in utilizing space that was inadequate electrically and mechanically. Of almost equal inconvenience had been the problem of rearranging the relationship of laboratories to suit the owner's concept of the approach to a scientific problem. The rearrangement of laboratory facilities was time consuming, costly and often impracticable.

The management had a keen desire not only to provide a better place for the workers but they also asked the architects to provide a design that represented the utmost in an economic approach to the problem of flexibility.

The research problem is usually attacked by a team of two to twelve scientific personnel. In the case of Bell Telephone Laboratories, this team may be a combination of chemists, physicists, mechanical designers, and electrical engineers. They have found it desirable to juxtapose laboratory facilities required by these people in order to simplify supervisory and design procedures. Therefore the building must be adaptable to changes that can be made economically and rapidly with the minimum of inconvenience to the occupants of neighboring space.

TYPES OF SPACE

Before any drawings were made, the architects conducted a survey of the space then housing the functions to be relocated in Murray Hill. This area survey was tabulated by function, that is, laboratories, single and group offices, shops, files, blueprinting facilities and drafting rooms.

It became apparent that in a sizeable fraction of the total space, laboratory services would not be needed, which led to the development of the "T" (see figure IV.55) and the cross plan forms, referred to above. The small office and the offices of the executives, as well as the smaller conference rooms and drafting rooms, were located in the office wing. No attic, laboratory services or heavy floor loadings were required here. It was also evident that the module for these functions would have different dimensions from the ideal module suitable to the technical areas.

In the technical space, of prime importance was the basic two, four or six man laboratory. Other functions which might be suitably housed in similar space, were shops, stock rooms, file rooms, stenographic groups, electrical circuit design rooms and drafting rooms. Thus it was decided to separate the various functions into two fundamental categories based on the following facts: 1. that space requirements were similar in the general dimensional aspects and 2. that the management realized that since limiting the amount of space having laboratory facilities was good economy, somewhat more than the minimum space having such facilities must be built. As a consequence certain functions that could have been assigned to the office wing were assigned to the technical area, as a future cushion.

The next step was to examine the functions assigned to the technical area to determine whether one space module would suit all the functions. It was found that the four man and larger laboratory, shops, stock rooms, drafting rooms and electric circuit design groups could use a greater depth of space than would be ideal for the group office, the secretarial offices and the small laboratory.

DIMENSIONAL CONSIDERATIONS

The height, width and depth of the laboratory module was derived by considering the needs of the two general classifications of function for which the space was to be designed. In searching for a common multiple, typical layouts were made of the most desirable arrangement of laboratories, stock rooms, drafting rooms, design groups and stenographic groups.

The optimum laboratory for two men appeared to be an arrangement in which the line of furniture was perpendicular to the outside wall, with a center aisle of approximately five to seven feet in width with a room depth of approximately 20 feet. Standardized 2'0" by 5'0" laboratory tables were already being used.

In the larger laboratories it seemed desirable to have laboratory tables perpendicular to the outside wall against the room partitions with either a large space in the center of the room or one or more island groups of tables arranged perpendicular to the outside wall. These laboratories would be adequate for the use of four or more persons and the arrangement seemed to satisfy the needs of the chemists, physicists, and the mechanical and electrical engineers. The most satisfactory depth for the larger area was approximately 25 feet. Thus as many as five 5-foot tables could be placed along a wall, or aisles could be maintained between the window and the island and between the island and the corridor and still leave a long enough island. The dimension parallel to the exterior wall with one island arrangement appeared to be satisfactory from a safety standpoint, if the aisle were reduced in width as compared to that required in the two-man laboratory. Accordingly, these laboratories seem to reach their optimum at a depth of 25 feet and a width of 18 feet or more.

The best layout for office desks was to place them in parallel rows perpendicular to the exterior wall on 6-foot centers, with window light coming from the left The layout for two and three man offices with the

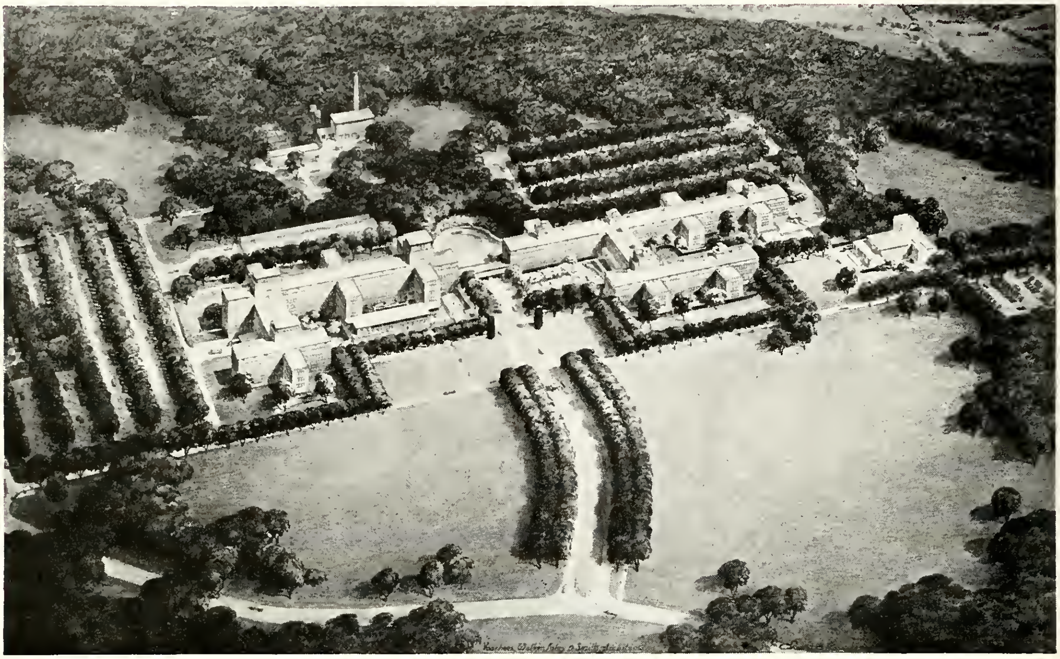


Figure IV.54 General airplane view of Bell Telephone Laboratories at Murray Hill, New Jersey.

necessary files and bookshelves showed that a space approximately 20′ deep by 11′ or 12′ wide gave a multiplicity of excellent arrangements. (See figure IV.55.)

It now began to appear that the depth of the two general categories of laboratory space could be fixed at approximately 25 feet and 20 feet. Inasmuch as the desks and laboratory tables were 5 feet long, these dimensions were made a few inches more than the dimensions stated, in order to facilitate the movement of furniture.

It was felt desirable, if possible, to establish a single module width. As will be seen from the above, the common 6 foot multiple for the laboratories would suit the optimum arrangement for the two man laboratory, approximately 12 feet in width, and serve equally well in an 18 foot laboratory, having one island, and the 24 foot laboratory having a large open space in the center between two groups of wall tables. Thirty feet would provide a satisfactory laboratory arrangement having two island tables. The aisle widths provided in these laboratories were checked for both safety and convenience and it was found that 6 feet was quite satisfactory.

In considering the desks and chairs used by the other types or workers, the 6 foot dimension also proved satisfactory because group offices could be arranged in any multiple of three or more, making the minimum group office 18′0″ by 25′0″. These dimensions suited all the types of space in the categories requiring the greater depth, since the shops and stock units could easily be adjusted on a non-module basis to fit almost any large space. The 6 foot dimension also worked out satisfactorily for two and three person offices for both engineers and secretaries.

In determining the height of the module, the height of distillation racks, the basic telephone apparatus frame, chemical fume hoods, good ventilation and good lighting had to be considered. The telephone switchboard frame is 11 feet 6 inches in height. With the allowance of a few inches for clearance and several inches for acoustical material, the determined height became 11 feet 11 inches to the underside of the slab. This dimension was then checked against the other features requiring consideration of height. It was also determined that the encroachment on this height of beams and girders would not be detrimental to the use of the space.

ARCHITECTURAL CONSIDERATIONS

Metal partitions were found to perform the function of flexibility because they could be taken down and reinstalled without creating noise or dust. They were as fire resistant as the commonly used plastered block

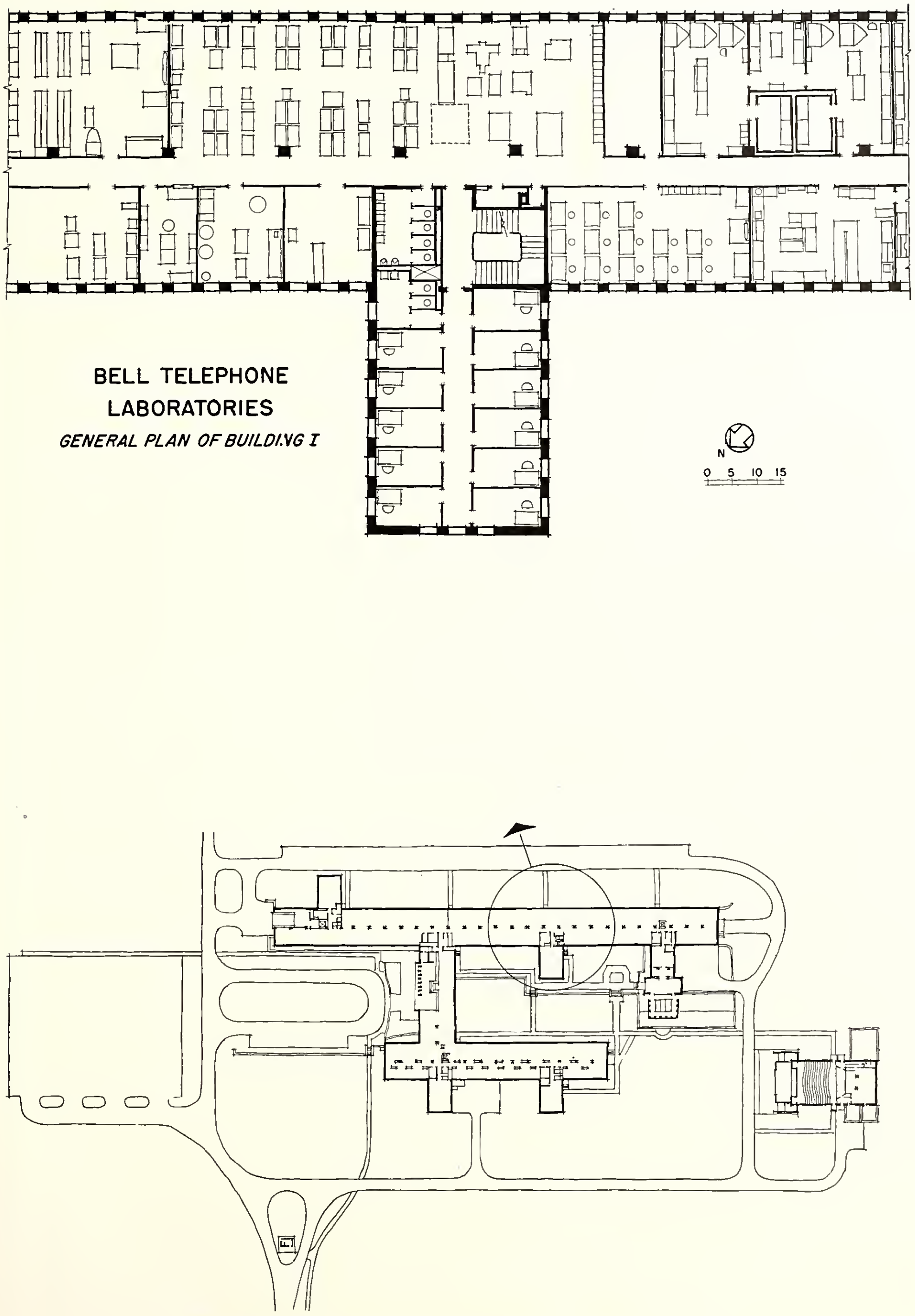


Figure IV.55 The general plan of Building 1 (first project) with detail of "Tee" unit.

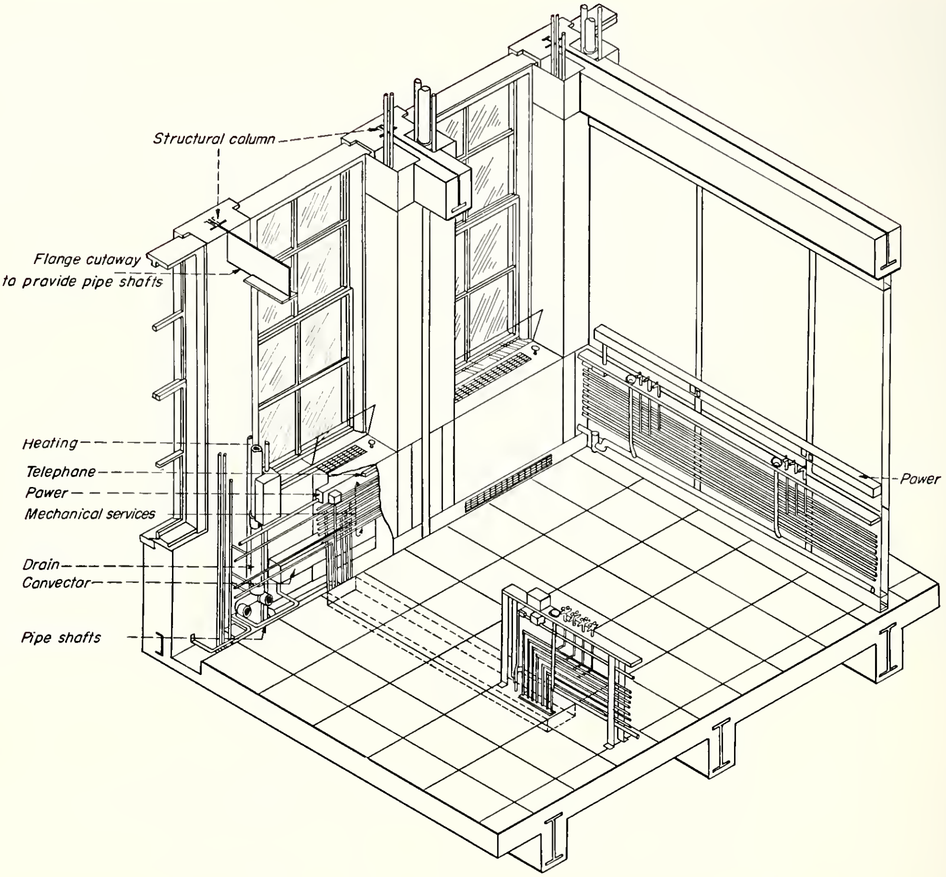


Figure IV.56 Isometric diagram of two laboratory modules. The outside wall with piers at regular intervals is used as a source of all services. Each building module contains natural and artificial light and access to mechanical and electrical services.

partitions and had the capability of readily receiving shelves, service strips, mechanical services and the multiplicity of other items that the scientists might find need for attaching to their partitions.

Double-hung windows were chosen because they could be opened at the top for thorough ventilation. They also met the requirement that some ventilation be obtained even during rainstorms (since the building was not entirely mechanically ventilated). Another requirement was that no columns project into the room space. The selection of the materials for the slab structure and the arrangement of the beams and girders were utilized to break up reflecting sound waves, so that very little acoustical material was necessary to produce a relatively good absorption characteristic.

MECHANICAL CONSIDERATIONS

Mechanical ventilation for fume hoods was required in all portions of the building to be used for chemistry. While this was not necessary in the other portions of the building, the building is so designed that mechanical ventilation or air conditioning may be added in the future within the same space and general arrangement as the mechanical ventilation being initially installed in the chemistry section. Since it was necessary to be able to place a fume hood at any 6 foot interval in the building and on either side of a possible subdividing partition, it was also necessary to supply air to each module.

The design of the basic distribution system uncovered many problems. Any system of horizontal mains on each floor produces the problem of servicing through other occupied floors and thus interferes with laboratory work. Such an arrangement also has the objection of being somewhat inaccessible if covered, and if left uncovered in a corridor ceiling it raises additional problems of housekeeping and appearance. Thus, a basement distribution scheme with vertical risers feeding each module was indicated. A system of distribution which brings the risers up the corridor wall results in too thick walls at the entrances to the laboratories and considerably inhibits the arrangement of doors. This led to the adoption of vertical risers in the outside walls at each 6 foot interval. A number of economic studies brought about the final determination of a drain riser on every 6 foot point, with the other services alternating on the various 6 foot points and being repeated every 24 feet. Underneath the windows horizontal branches were carried to each module from the risers. Such an arrangement permitted the servicing of an island table by means of a small floor trench placed on the center line of the window. The floor trench in this location did not interfere with the partitioning on the 6 foot points and also served most economically the standardized position of the island arrangement in the center of an 18 foot laboratory (see figures IV.56 and IV.57). Under this arrangement, laboratory services can be added so readily that a considerable economy was effected by not initially installing too many services.

ELECTRICAL CONSIDERATIONS

It was required that there be a circuit breaker for each laboratory. In addition, telephone requirements were particularly important in this building. Since no laboratory could be less than 12 feet in width, both requirements were solved by having a telephone riser alternate with a laboratory power riser on 12 foot centers. This assured the location of a service breaker at the power riser in each laboratory (see figures IV.56 and IV.57). A wire trough underneath the window-sill enabled any system of partitions or island tables to be served with the same ease as the mechanical services. Because of the inherent requirement of flexibility, lighting switches might be required at any point along the corridor wall. As a consequence, the lighting power panels were located on the center structural columns with each panel serving four modules. The partition served as a wireway for the switch legs, which are installed as required.

STRUCTURAL CONSIDERATIONS

The height of the building had been determined at three stories, plus an attic and a basement, thus the indicated structure became either a concrete or fireproofed structural steel frame. The economy of the structural system—that is, the arrangement of beams, girders, and columns—is such that the usual differences are somewhat small as compared to the costs of mechanical and electrical work. The architects

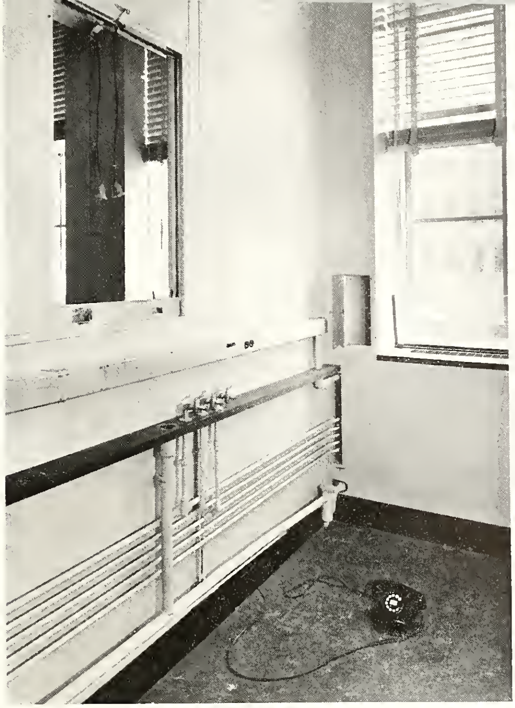
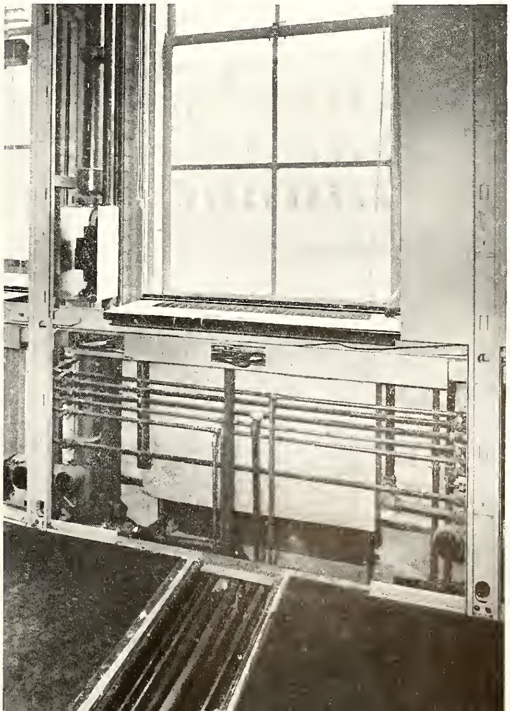


Figure IV.57 Services to all laboratory tables are simply supported on inserts in the steel partitions. A wire trough permits complete flexibility of electrical outlets. Chemical laboratories are provided with a secondary means of escape. This panel may be seen in its lowered position at the upper left.

Figure IV.58 The same view of the exterior wall as presented in figure IV.57, except that the metal wainscot covering the mechanical services has been removed. Note the horizontal power raceway and the trench leading to island services.



therefore designed a structural system to suit not only the convenience of the occupants but also the overall economy of the architectural, mechanical and electrical considerations. The flat exterior wall indicated the use of a small exterior wall column. The requirement for partitioning on 6 foot centers suggested the use of a beam at this interval in order to conserve on the height of partitions and provide uniformity. The mechanical services, with the necessary floor slots both at the exterior wall and the center line of the building, had its effect on the structural design. Again the use of metal partitions suggested that all beams and girders be of the same depth.

DESCRIPTION OF THE MODULE AS DESIGNED

Finally, having integrated the requirements of the owner with those of the structure, the basic 6 foot module was designed. Modules had two different dimensions in depth: on one side of the corridor this dimension was somewhat in excess of 18 feet, and on the other side more than 25 feet. Each module contains all of its own architectural, mechanical, electrical and structural features.

The window provides light and ventilation. Below the window is the heating unit for the module. The piers on either side of the window contain the structural columns, which by using car-building bulb angles, are small enough to keep the structural system within the thickness of the masonry wall. Below the window the flush metal radiator enclosure which covers the service shafts at each column point, as well as forming the reveal of the window, provides an architectural finish that matches that of the partition. This wainscot also permits the installation of the vertical line of partitions at each 6 foot point. On either side of the center line of the pier a shadow box is formed so that the mechanical services from the service distribution points behind the partition may be run perpendicular to the outside wall on the face of the subdividing partitions. The lighting of the module is an indirect type using a silvered bulb and annular ring type of incandescent fixture. The structural beams on the 6 foot center points give a surprising amount of acoustical value to the space. On the exterior of the building, the selection of the brick and the determination of the widths of the piers and windows were arranged to benefit from the full economy of the repetitive element. The brick unit is 11⅜ inches in length, with a ⅝ inch joint which enabled the designer to produce both the pier and the window opening, as well as the spandrel, in a combination of full brick units. The window is four units wide and the pier two units. Along the corridor wall, the door is usually placed in the center of the laboratory. Outlets for fume hood connections are on either side of the partition points. Exhaust grilles cover these openings where no hoods are required. The supply grilles are located beside the exhaust outlets.

The entire assembly of laboratory requirements produces an entity that is structurally sound, convenient and satisfying in appearance.

9

JOHNS-MANVILLE RESEARCH CENTER

Edward M. Jenkins

Johns-Manville Research Center, Manville, New Jersey

The Johns-Manville Research Center is located on a 93-acre tract of land near Manville, New Jersey, about 40 miles west of New York City. Five of the six buildings planned as the initial group have been completed. Buildings of this Research Center involve a new concept of industrial research construction. Industrial research requires simplicity of construction, versatility in use of space and provision for ease in future expansion. In Johns-Manville's new Research Center, the architects, Shreve, Lamb and Harmon of New York, have solved these requirements by a new approach to the problem, and their plan has been carefully executed by the general contractor, Turner Construction Company of New York, in the completion of all but the final building of the six planned for the group.

FACTORS INFLUENCING DESIGN

Both the nature of the organization and the design of the Johns-Manville Research Center are greatly affected by two considerations.

First, in Johns-Manville, the Research and Development organization is responsible for all experimental work which affects the quality of the product. This is a broad assignment and almost all of the work involved in carrying out the responsibility is done by the organization located at the Research Center. The group of men at the Research Center is responsible not only for what is ordinarily considered as research but also for product development—for the design, construction and operation of experimental machinery involved in the processes and for actually taking the process into the factory and operating it successfully on factory-scale equipment before turning it over to the manufacturing organization.

Second, is the extreme diversity of the Johns-Manville business. Almost every large company manufactures many different products but few companies the size of Johns-Manville are involved in so many unrelated operations. In attempting to describe the range of activities, it is customary at Johns-Manville to say that interest is in providing protection against fire, weather and wear, and in controlling sound, heat and motion. Even this, however, leaves out a considerable interest in filtration aids and fillers.

The organization at the Research Center is composed at present of more than 400 people, about equally divided between technical graduates, non-graduate assistants and supporting staff which includes clerical, maintenance and machine shop crews. The Research and Development organization is divided into 21 sections. Each of these sections is charged with what amounts to research and development responsibility for a separate industry. For example, the section working on asphalt products is quite distinct from the section working on asbestos-cement boards, which in turn has little relationship to the section working on wood pulp boards, which again has nothing in common with the section working on filter aids. Each section is responsible for all technical activities connected with its particular business from analyzing sales needs to putting a new process in the factories.

The sections are grouped under five Research Managers, each of whom is practically a research director for a major portion of the business. The managers report to the Director of the Research Center.

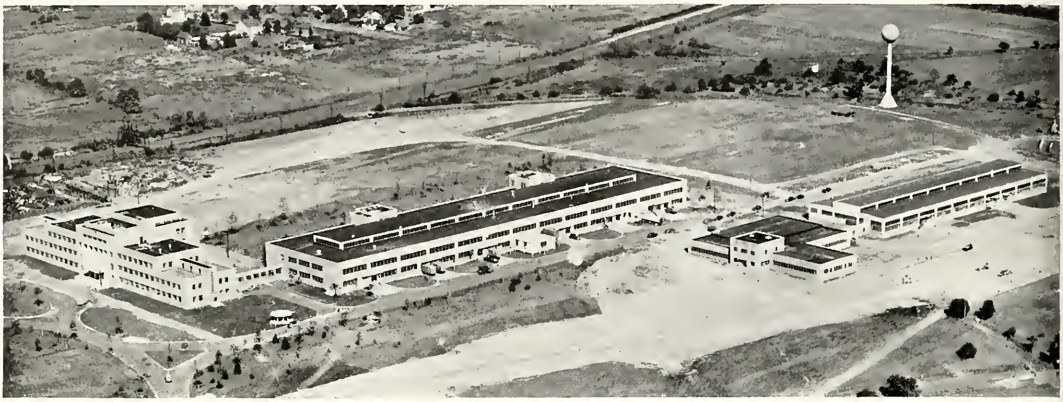


Figure IV.59 Looking east on the Johns-Manville Research Center. Left, research building; center, product development building which encloses pilot plant area; right, foreground, engineering building; right, mechanical building. The filtration plant is off the photograph to the right.

In laying out the Johns-Manville Research Center, much emphasis was placed upon providing for future expansion. The immediate program calls for providing all of the necessary services including a large water purification plant, the construction of two product development buildings, a research and administrative building, a mechanical shop building and an engineering building.

BASIS OF DESIGN

The last twenty years have seen a tremendous growth in the size of industrial research organizations, but it is only recently that proper attention has been given to the problem of providing facilities commensurate with the importance of such work. Some notable industrial laboratories have been built, but much industrial research work has been done in converted warehouses or factory buildings. In some cases, new industrial research laboratories have tended to follow traditional collegiate patterns.

Gradually, however, the amount of money spent on industrial research has made it imperative that special facilities be provided to insure the most efficient utilization of the money spent. As a result, there is at the present time a tremendous program of active and contemplated construction of industrial research laboratories.

More important than the size of the expansion program is the fact that an entirely new kind of laboratory construction has been evolved. Industrial research has demanded simplicity, versatility of use for the space provided and ease of further expansion. The architects have met the new demand by taking a novel approach to the problem and most of the new laboratories are being designed to conform to these recent ideas.

The construction of the latest industrial research laboratories has been pursued along two lines: first, the use of modular design in which a laboratory becomes simply an assembly of standard work units; and second, the adaptation to laboratory design of certain practices which have become established in large office building construction.

The new thinking regarding laboratory design starts with the idea that laboratory work, even of widely different types, requires much the same space and facilities. It should, therefore, be possible to design a standard work unit or module which could be used for a wide variety of different purposes by simply changing service outlets and furniture. The design of a laboratory, therefore, becomes basically the design of the most adaptable unit or module, the grouping of a sufficient number of these units into a simple building, and the providing of supplementary facilities such as pilot plants, cafeterias, libraries, etc. When such an approach is first suggested to a laboratory organization, they generally consider their work as being too specialized for such a standardized scheme, but laboratories of this sort have proved so successful in practice that the standardized module design has become the basis of almost all new construction of large industrial laboratories.

Rather general agreement has been reached regarding the shape of the standard module for industrial use, although there is still considerable difference of opinion regarding the most desirable size. The standard unit is a slot with work tables down each side, a window at one end, and an access door from a corridor at the other. This is in contrast with the old idea of considering a laboratory as a room with tables around the walls and an island table in the center. Some people favor a unit with a work table down one side of the aisle and storage cabinets on the other, but most designers believe sufficient storage space can be provided below table level or in supplementary cabinets replacing a limited number of table units. A laboratory can consist of one or more units combined to form a single room. An effort is made to include within the slot or unit the facilities which the worker will require so as to minimize the amount of traveling he will have to do from his work area, and every effort is made to avoid making it necessary or convenient for other people to pass through his working space (see figure IV.60).

The size of the standard unit varies considerably with the nature of the work to be carried on and the willingness to spend money to increase the convenience and the spaciousness of the laboratory. The absolute minimum width would include a 3½-foot aisle with 2-foot tables on either side, which, with partitions, would give a unit width of 8 feet. This, however, is too cramped for good practice, and 9 feet in width from partition center to partition center, or from table back to table back, is the minimum of good practice even when only small articles are to be handled. A 10-foot width is considered better practice and 11 feet is desirable where bulky articles are involved. In any case, the aisle should be wide enough so the men working at opposite tables do not interfere with each other, and real spaciousness is achieved if they are far enough apart so that a third man can pass between them without disturbing their activities. Unit lengths vary from 20 to 32 feet. In determining the length, it is desirable to provide clear space within the partitions in multiples of 2 feet since standard furniture and cabinets usually come in 4-foot or 2-foot lengths. Sometimes two different unit lengths are provided by using an off-center corridor. In this case, a single row of center building supports is provided with the corridor running along one side of the supports. This gives long units on one side of the corridor and short units on the other.

After construction of several full-scale complete working units and considering the type of work to be housed at the Johns-Manville Research Center, a unit size of 11 feet by 26 feet was selected. The partition thickness is subtracted from the 11-foot width so that the clear width is 10 feet 6 inches. The 26-foot length is the clear inside dimension.

MOVABLE PARTITIONS

In order to convert a working unit readily from one use to another, it is customary industrial practice to use a variety of standardized bench and table units. These units are available in 2-foot and 4-foot lengths and it is relatively simple to substitute one type of table unit for another when the laboratory unit is converted from one type of use to another.

To achieve complete versatility of use for the space provided, industrial laboratory design has adopted the relocatable partitions which have become standard for certain types of modern office building construction.

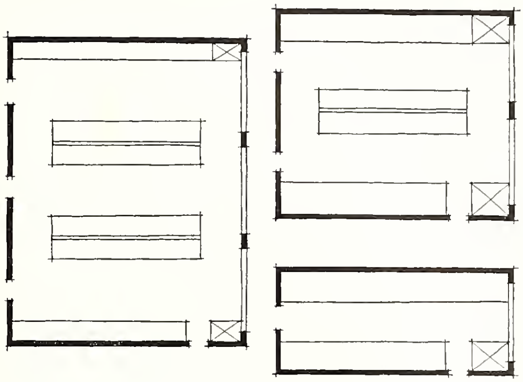
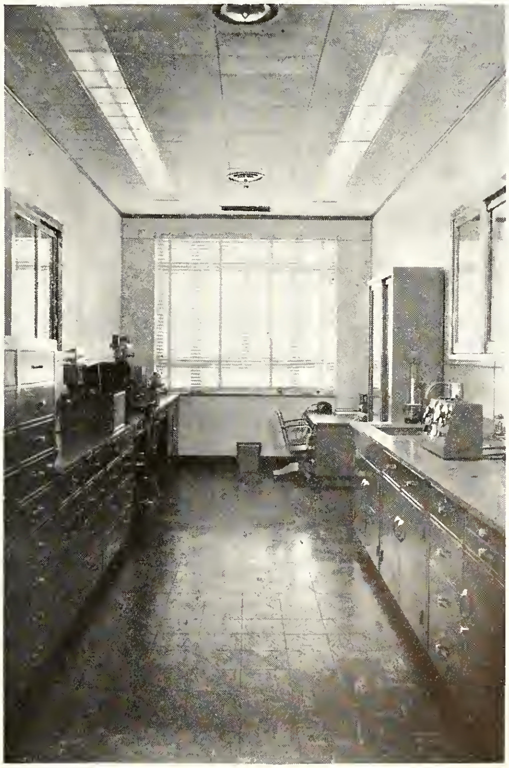


Figure IV.60 A laboratory may contain one, two, three, or more work units.

Figure IV.61 Single laboratory unit. Clear width is 10′ 6″; clear length is 26′ 0″.



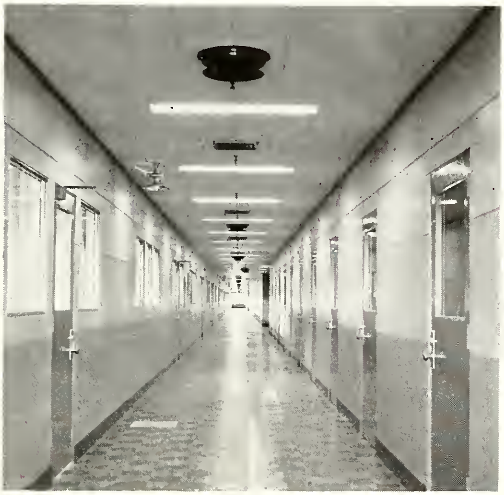
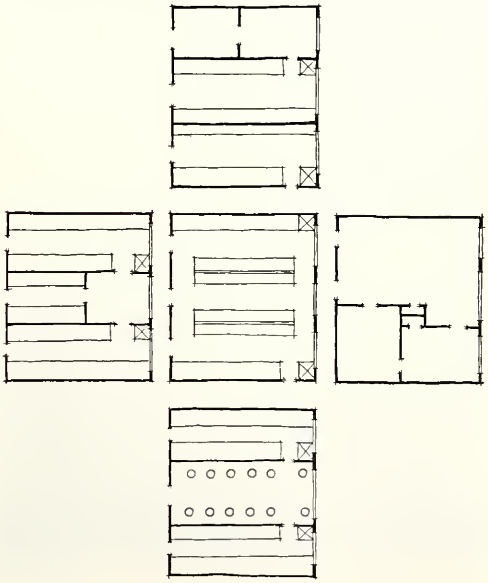


Figure IV.62 Corridor in the product development building with laboratory units on right and pilot plant area on left; sheet application is horizontal in this corridor.

Figure IV.63 An illustration of alternate uses of a three-unit space.



These partitions are ordinarily spoken of as "movable", although they are not movable in the same sense as sliding or folding partitions. However, they are so constructed that properly trained personnel can take them down and re-erect them in a short space of time without any of the mess or confusion involved in relocating even the simplest masonry partitions.

The relocatable partitions used at Johns-Manville Research Center are constructed of "Transitone" asbestos-cement sheets, manufactured by Johns-Manville, hung on light-weight metal studs that are held in place top and bottom by metal channels attached to the floor and ceiling. The "Transitone" sheets are integrally colored and provide permanent decoration that does not require finishing after erection. The wall sheets are attached to the metal studs with invisible spring fasteners which assure lasting positive fastening without rattle and yet allow easy demounting of the sheets.

The most common use of these movable partitions is to vary the grouping of work units into rooms of different sizes. For this purpose, it is only necessary to remove and relocate the cross partitions between fixed exterior and corridor walls. If it is desirable to relocate the doors in the corridors, it is possible to remodel the corridor wall as well, although this can be avoided by providing a separate door in the original corridor wall for each unit, so that the relocating of the cross partitions does not upset the individual access to each working space. The movable partitions can also be used, if desired, to divide a unit into smaller rooms for specialized purposes.

VERSATILITY OF CONSTRUCTION

Laboratory design of the kind used at the Johns-Manville Research Center, using the duplication of standard work units, movable furniture and piping, relocatable partitions, and providing a variation of possible services, has almost complete versatility of use for the space provided. For example, three work units might be used as one large laboratory, be subdivided into three small individual laboratories, or be used as two small laboratories with a common equipment room between which might be either a single space or a space easily dividable into a dark room and a sample-preparation room. Or the three units might be modified to provide a two-unit laboratory and an office with a small personal laboratory, or could provide a secretary's office, a private office, a full-size private laboratory, and a supplementary equipment room, or might be used to provide division headquarters consisting of a private office, a conference room, and a large secretarial, stenographic and filing space. In present construction at Research Center, nearly all of these varied uses have occurred. By changing the nature of the furniture and the type of services available, the space could be used at one time for chemical work and at another time for experimental work in physics. It might be used for laboratory purposes or, again, it might be subdivided so that part of it could be used to house community equipment, such as ovens, grinding machines, etc. To convert from any one of these uses to any one of the others is a matter of a few days' work (see figure IV.63).

Perhaps even more important than the versatility of usage is the possibility of expanding the size of the laboratory and then readjusting the space so that it will be as efficiently distributed as if the building had originally been planned for the enlarged size. As a simple illustration: if the original building was designed to provide ten units for chemical work and ten units for work on physics and it should be later decided to add an additional ten units of space, both the chemical and the physical operations could be expanded five units by a rearrangement of partitions and facilities with the space as efficiently distributed and located as if the plan had originally been made for thirty units.

Space designed for laboratory use is expensive to construct so that in designing the Johns-Manville Research Center, considerable effort has been made to provide cafeterias, libraries, auditoriums, file rooms and offices convenient to the laboratory space but at a lower construction cost. In some cases, this is accomplished by constructing a simple modular laboratory building and adding short side wings to house offices. At the Research Center, a section of building without laboratory piping, fume exhausts, etc., was set into a standard laboratory structure. There are a number of other obvious approaches to the solution of this problem, all having the general objective of using the expensive space equipped with services, fume exhausts, etc., primarily for actual experimental work.

SERVICES

Modern laboratory practice provides gas, water and a wide variety of other services on both sides of each unit, or, in other words, between each two adjacent laboratories. It is standard practice to make all of the potentially desired services available at each location but to pipe to the tables only those services which are immediately needed. There are three more or less standard ways of carrying these services to the point from which they can be tapped off to serve the working units. One is to have the main distributing feeders in the basement and bring individual risers up the outside wall between the windows so that they can be tapped off from the outside wall to provide facilities along the backs of the tables. The second is similar except that the risers come up shafts at the intersection of the unit limits with the interior corridor walls. The third and more traditional system is to run the main service pipes under the floor slab and to tap off up through the floor in floor boxes or sleeves. The under-floor distribution system was selected for the Research Center because of simplicity of construction and easy access for alterations and repairs.

There are also a variety of ways in which the services may be run from outlet boxes in the floor or in the end partitions to the proper outlets along the tables. The customary method of carrying piping on a pipe rack attached to the wall back of the table run and below the tabletop level cuts down somewhat on the storage space in the cabinets and requires moving the furniture to work on the piping. The asbestos-cement partitions used at Research Center are hollow and carry within the wall both supply and drainage piping.

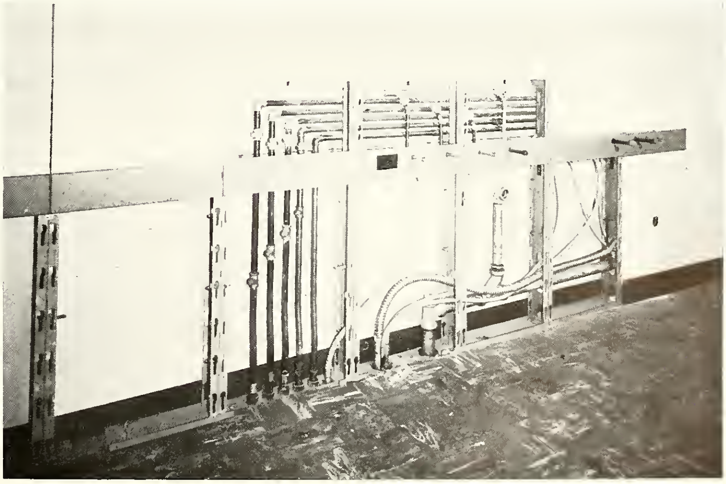


Figure IV.64 Service piping, drainage piping, and electrical supply within a movable wall; the horizontal dark band pierced by piping is the table splash. Access panels are above the splash; three panels are removed to show horizontal piping.

Supply lines are behind removable access panels set above the table level. Access to service piping is thus provided without disturbing furniture. A single service pipe is tapped off to both sides of the wall. Chemical lead, steel, and wrought iron drain lines were provided. All piping was sectionalized and related to the wall construction through the 2-foot stud spacing unit. Actually, all service and drainage piping was cut in 4-foot lengths (two units), and all cutting and threading was done before any partition work was started. A group of service outlets or a sink were centered on a 2-foot unit point (stud center). Sinks or service groups can be installed at any 4-foot interval along the cross walls at the time the partition is constructed or at any later date. By so governing the location of service outlet groups and sinks, a relation was established between partition construction, piping and piping outlets, and furniture.

CEILINGS AND FLOORS

To avoid the poor appearance and difficult house cleaning of exposed ducts and piping, industrial laboratory design has borrowed another standard procedure from large office building construction—namely, the use of hung metal ceilings. These are simply suspended false ceilings carried on a light metal framework which conceal all of the overhead piping and duct work. At Johns-Manville Research Center, the ceiling surface is composed of 12" by 24"-light-metal perforated pans which slip into the metal framework and may be quickly removed and replaced so as to give ready access to the miscellaneous piping, wiring and duct work which they conceal. The pans are perforated and fitted with sound-absorbing pads, and are an effective acoustical ceiling. The ceilings are designed so that troffers can be substituted for some of the metal pans, providing recessed fluorescent lighting which may be placed anywhere in the ceiling with the wiring concealed between the floor slab and the hung ceiling. The hung ceiling also obscures lines to supply fire alarm and sprinkler heads as well as air inlets and speakers for the call system.

Floors throughout the laboratory, office and passageway spaces are of a special tile similar in appearance to asphalt tile. Exception was made to this tile surface only in the executive offices where carpeting was used. The floor tile has sufficient resilience so that further cushioning of the concrete floor slab has not been necessary.

FURNITURE

Metal laboratory furniture was used throughout the Johns-Manville Research Center. To reduce kinds and sizes of furniture, twenty-two standard types were provided and individual selections made from these. Other necessary types of furniture were classed as specials. About 97% of the furniture in the Product Development Building could be confined to the standard types.

All furniture assembly, including tops, was done dry; that is, without using any cements, mastics, or the like. Tops were a special asbestos-cement product and were fastened to the tables with sheet metal screws in drilled holes on the underside of the top. Waterproofing of the joint between two tables was done with two metal shapes, one fastened to each top with sheet metal

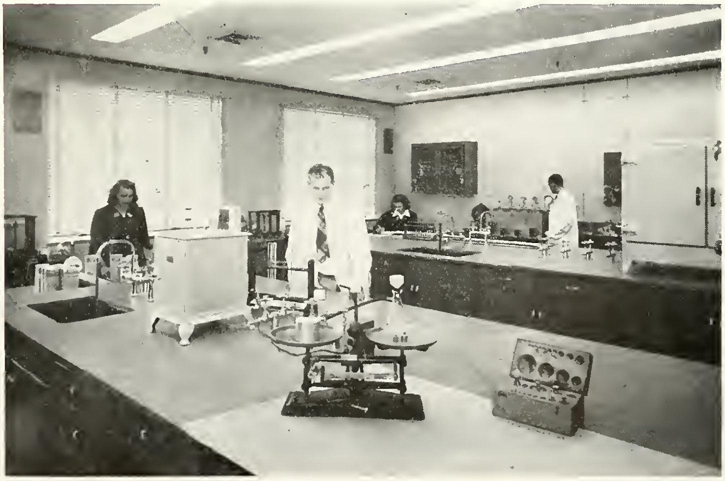


Figure IV.65 Triple laboratory unit (note acoustical ceiling and recessed fluorescent lighting).

screws, and a strip of self-expanding cork (see figure IV.66).

The self-expanding cork has the property of swelling when wet and remaining swelled upon drying, thus sealing the crack by pressure. An asbestos-cement strip of the same material and color as the tops was mounted as a part of the wall surfacing. The strip was so placed that it extended about 6 inches above the tabletop forming a dark colored splash. No seal was used in the joint between the top and the splash. All tabletops were related to the piping and wall structure being 2 and 4 feet in length. The tables, themselves, were 2 inches shorter than the tops to allow room for the joint sealing metal shapes. Also the shorter furniture unit provides an overhang on top ends to match that along the front edge of the top at any point where a table run ends or is interrupted. Removal or alteration of the furniture can be done more easily because of the joint type and the top ends, exposed by the change, are not marred by unsightly cuts, holes, or hardened cement. Sinks were waterproofed to the tops using a ½-inch wide sponge rubber strip, ¼-inch thick cemented to the flat sink rim only with rubber cement. Pressure supplied by the sink support screws sealed the sponge rubber gasket tightly against the top.

Top joints occur opposite a joint in the wall sheet (splash) because of the unit relation between furniture and walls giving a pleasing symmetry. More important, the drainage cup below each water service cock is in its proper place as is the sink outlet. Inter-relation of walls, piping and furniture made possible simple and rapid assembly of walls, piping, furniture and tops.

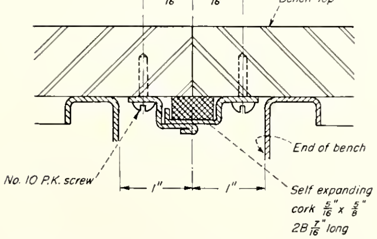
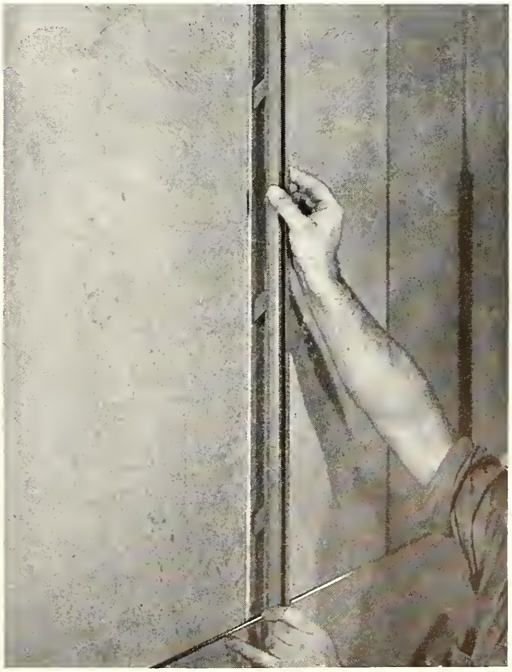


Figure IV.66 End view of the metal parts and self-expanding cork used in all joints between tabletops.

WALL HANGER SYSTEM

A familiar problem in laboratory construction is provision for the attachment of weights quickly and easily to a laboratory wall. At the Research Center, a hanger system has been devised that provides at each wall sheet joint (2-foot centers) a hanger that will support several hundred pounds and can run from floor to ceiling, or tabletop to ceiling, or fraction thereof, if necessary. The plate web of the steel wall stud is provided with slots angling downward at 45° on 8-inch centers. Normally, the ⅛-inch space between sheets that allows access to the slotted stud web is closed with a stainless steel bead. The bead may be lifted out and replaced with a metal hanger bar and casing, having ⅜-inch tapped holes on 4-inch centers. The hanger bar casing engages the slots in the web. Various lengths of hanger bars are available at Research Center so that apparatus may be mounted clear of the working top, heavy parts can be properly held near the wall surface and cabinets and shelving attached. Many other wall attachment problems can be solved with the hanger system.

Figure IV.67 Hanger bar casing being hooked into the wall; the bar with tapped holes slides inside the casing and is supported at the casing top.



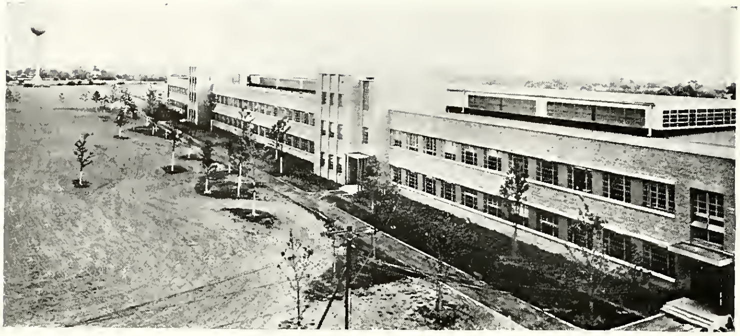


Figure IV.68 Product Development building provides pilot plant areas adjacent to laboratory spaces.

PILOT PLANT FACILITIES

A great deal of thought was given in the design of the first Product Development building to provide low-cost pilot plant space conveniently adjacent to the laboratories so that close correlation between laboratory research work and large-scale experimental manufacturing can be maintained.

Emphasis has been placed upon pilot plant equipment in the Johns-Manville Research Center. A great many developments require experimental work on plant-scale equipment, and it has been found that it is wasteful to try to conduct experimental work on actual plant facilities. Johns-Manville is, therefore, proceeding to set up equipment in the Research Center so that practically every one of the company's operations can be conducted on a scale sufficiently close to production practice to keep to a minimum the number of times it will be necessary to interrupt factory operations. Also, when experimental work is done on factory equipment, there is an early limit to the machine changes which can practically be made; whereas in the pilot plant area, it is routine to try all the novel ideas presented. Any experimental use of factory equipment naturally requires arrangements to fit the work with the factory schedules which results in delays in the programs. Some of the Johns-Manville factories are at a considerable distance from the Research Center so that additional delays and expense would occur through the necessity for long-distance traveling of research men to the factory. The accumulation of materials at a distant factory also slows the work. As the scheduling and operation of a factory experiment involves such a number of difficulties and expenses, there is a tendency to avoid experimental factory runs as far as possible, taking to the factory only a few of the surer possibilities. These limitations placed upon the research men are largely removed by the pilot plant equipment now being made available at the Research Center Product Development building.

There is still another object in providing pilot plant space at Research Center. In every new process, there is always some key step or some particular piece of equipment which is entirely new and upon which the success of the projected process depends. It is proposed as a practice to build or have built any critical piece of equipment, full scale, and place the equipment on the pilot plant floor until it is operating smoothly. The proven key piece of equipment can then be transferred into the plant with confidence that the new process will be in correct operation in a minimum of time.

The Product Development building has been divided lengthwise into two parts. Thirty-six feet of width of the building is a two-story building with a glass enclosed promenade running the entire 572-feet length of the building on each floor. The balance of the width, 100 feet, is a typical factory building. The factory area is divided into ten separate pilot plants corresponding to the products under investigation in the laboratories facing the plants which are equipped with the necessary factory machinery needed for the research and development manufacture of products. The ten pilot plant spaces are allotted to work with asbestos fiber, "Transite" pipe, asbestos cement, paper and millboard, shingles, wood fiber board, asphalt products, material testing, magnesia, fillers and filtration.

There are ten more or less unrelated parts of Johns-Manville's businesses placed together in the first Product Development building. Each has its pilot plant area and adjacent laboratory space. It is obvious that the research needs of the various phases of the company's business, represented by the ten research groups in the Product Development building, will fluctuate from time to time so that expansion may be offset by contraction and no new construction will be necessary.

The first Product Development building is designed to accommodate wet operations requiring quantities of water. The Filtration Plant is designed to supply 1500 gallons/minute of finished water at 95 psi from the nearby Raritan River. Waste water from the Research Center is pre-chlorinated, settled and corrected for pH. Drinking water is pumped from wells. The concrete floors of the pilot plant area are provided with drainage-ways across the area at 22-foot intervals.

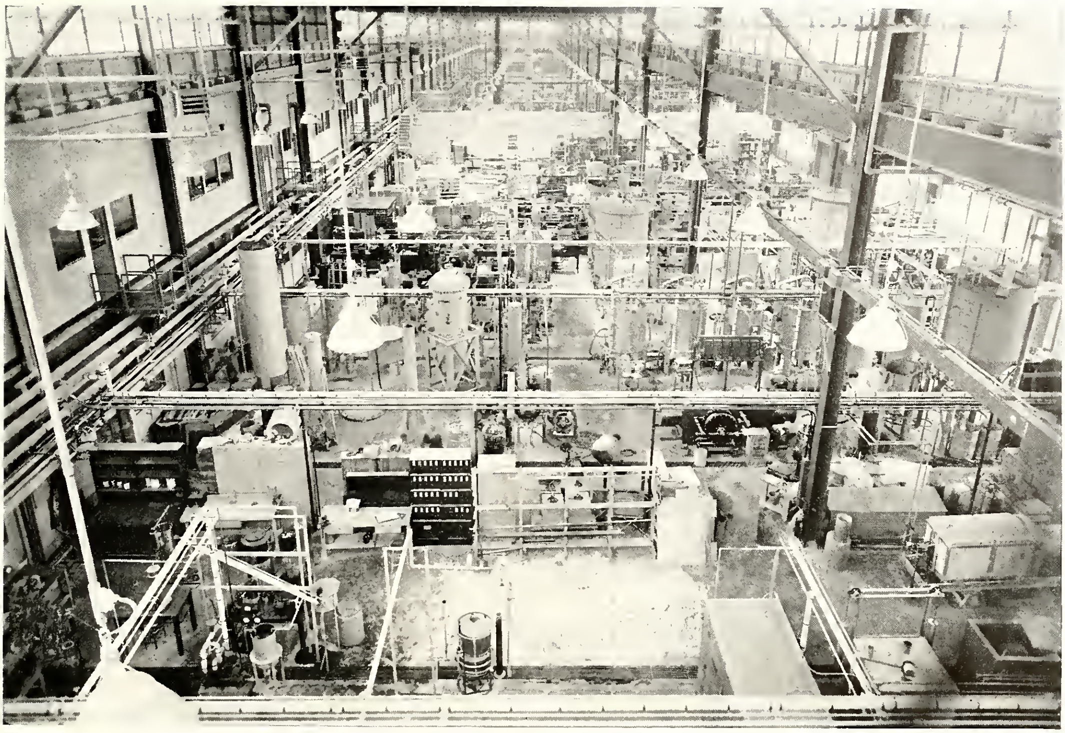
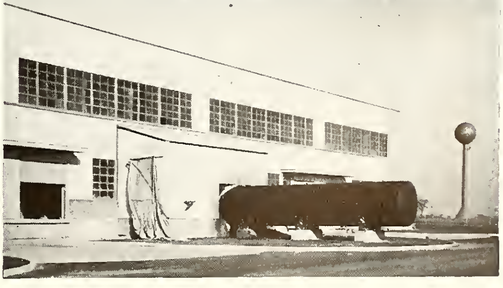


Figure IV.69 The observer is looking down the length of the pilot plant area of the Product Development building; to the left are the two floors of laboratories.

The rear wall of the factory side of the Product Development building also has unique construction features. It is made of "Transite" asbestos-cement sheets that are removable to permit temporary or permanent additions to house extra-long machinery or equipment. Trucks and trailers can also be "buttoned" on to the back of the building under special doorways, for the delivery of supplies or collection of refuse under weather-tight conditions.

Convenient access is provided between the second-floor laboratories and the pilot plant floor by adjustable metal stairways over the pilot plant floor that can be brought down at a number of points to avoid equipment or aisles, or may be removed altogether. Lighting in the pilot plant area is by 1000-watt incandescent high-bay units mounted at a height of 25 feet and spaced at 15 feet. Light is directed downward by crystal glass prismatic reflectors and the loss of high angle light is minimized by controlled redirection. The Product Development building is supplied with 440- and 110-volt AC electricity. The Research building has, in addition, regulated 110 AC voltage and 110-volt DC electricity. Steam is supplied to the Product Development building from the nearby Johns-Manville factory through an 8-inch line at 175 psi at the Research Center. Laboratories are air cooled. The pilot plant has factory-type clerestory window ventilation, special glass to arrest heat and reduce glare, but is not air cooled.

Figure IV.70 Piercing of the rear wall of the pilot plant area with a long steam tank; installation is semi-permanent.



10

ESSO RESEARCH CENTER — INDUSTRIAL LABORATORY

W. R. Hnot

Esso Engineering Department, Standard Oil Development Co., Linden, New Jersey

The Research Building is the main structure at the Esso Research Center, designed by Voorhees, Walker, Foley & Smith, and located at Linden, New Jersey. It houses the Research, Chemical, and Development Divisions of the Esso Laboratories and the Technical Library. The location of this building in the center of a landscaped 55-acre plot assures pleasant surroundings for the laboratory personnel and sufficient space for any future additions to the Research Center facilities. The building is of brick and steel construction, with three attached wings, in light-colored exterior treatment. Architecturally, it is characterized by flat-roofed construction with "Monel" metal clad overhangs or canopies and large windows.

The structure is a combination laboratory and office building and was designed to house 600 professional personnel and assistants. The main portion of the building is about 60'0" by 580'0" with the attached office wings measuring about 40'0" by 70'0" each. The main structure has a service floor, three combined laboratory and office floors, and a partially finished fourth floor. The end office wings are similar to the main structure but contain only three floors above grade, while the center wing is surmounted by a glass-enclosed library reading room. The three main floors and part of the fourth floor are air conditioned. Some of the areas have separate systems which utilize chemical dehumidifiers for humidity control and electrostatic filters to eliminate smoke, dust and pollen.

Elevators, stairs, lavatories and service closets are located in core areas at the juncture of the office wings and main structure. The passenger and combined freight and passenger elevators are of the completely automatic type.

The service floor houses most of the air-conditioning, heating and operating equipment as well as building maintenance offices, a telephone exchange, locker and shower room and laboratories and shops requiring heavy pieces of equipment.

An auditorium, seating approximately 150 people, is located on the first floor adjacent to the main entrance, and two conference rooms having a seating capacity of 75 each are located on the third floor.

The finished area of the fourth floor houses the library stacks and reading rooms, and a cafeteria; while the unfinished area is given over to ventilating equipment for exhausting the laboratory fume hoods and other parts of the building, some special air conditioning units and storage facilities.

GENERAL DESIGN OF THE BUILDING

The building is designed on a modular basis for simplicity and flexibility. To aid in establishing the modules, a test house was constructed in which mock-ups of typical office rooms, complete with furniture, laboratory rooms with tables, lights, hoods, service strips, service shafts with piping, conduits, ducts, safety shower and valve arrangements, toilet fixture and access to piping arrangements, were built and inspected by all concerned. In other words, a complete analysis was made before deciding to use any method or dimension.

After this detailed study, the building modules accepted were 10 feet for the main structure area, and 4 feet 2 inches for the office wing area. It was felt that a minimum width of 10 feet for a laboratory, and 8 feet 4 inches for a single office would be desirable. Larger laboratories or offices are in multiples of the module. The length of the laboratories or the offices is constant in all cases as shown by figures IV.72 and IV.73. As a result of this, all of the columns and girders along the length of the main structure are spaced 10 feet on centers, while in the office wings the column spacing is not as regular, but is based on the 4 foot 2 inch increment of dimension.

All interior walls are removable partitions of soundproofed steel and can be relocated with a minimum of time and disturbance should a larger or smaller room be desired.

All of the utilities and services for the laboratories are in uniform groups spaced 10 feet on centers, along the entire length of the building, thus giving extreme flexibility. The service lines or risers are located in service shafts adjacent to the corridor which run from the service floor to the fourth floor and are readily accessible through access doors from the corridors and laboratories. The services in each shaft are:

1. City gas
2. Cold water (process)
3. Hot water, 160°F
4. Steam (15 psi)
5. Compressed air (30 psi)
6. Nitrogen
7. Vacuum (22 inches Hg)
8. Electricity (120-volt to 440-volt, 1 and 3 phase)
9. Ventilation and exhaust ducts

STRUCTURAL DESIGN

Foundations

Soil characteristics called for the use of piles. The type used were steel casings driven to the underlying shale, blown out, and filled with concrete. The average length was 6 feet. Clusters of three were driven for each building column.

The steel columns were set directly on concrete pile caps, and the service floor reinforced concrete slab 12 inches thick was poured over the top of the pile caps and carried up around the steel columns to grade, to form curtain wall foundations.

The side walls below grade and the floor of the service floor were cement waterproofed from the inside. In some cases this waterproofing formed a finished surface.

Exterior Walls

The exterior or curtain walls are of brick, 12½ inches thick and are made up of face brick with common brick backing. The interior surface of all north walls was waterproofed with a mastic waterproofing compound, trowelled on. Window sills and belt courses are of limestone. Conventional copper pan flashing was used over lintels.

Expansion Joints

Because of the length of the building, (approximately 580 feet) it was decided to sectionalize the structure into three parts and connect them with expansion joints as shown by figure IV.73.

The expansion joints at the floors are bronze plates that slide over each other. The exterior wall and roof expansion joints are U-bends of lead covered copper. Calculations indicate a possible movement of 1.2 inches at each joint with a temperature differential of 70°F.

Roof

The roof of structural steel and gypsum plank design is flat, pitched to the center and drained. This design was chosen because of the advantage of speed in covering the building. The plank was covered with felt and mopped with hot asphalt as a temporary measure while the building was under construction. Later, when construction made it possible to complete the roof, a 2 inch layer of "Foamglass" insulation and a 20-year bonded 4-ply built-up tar and gravel roof was added. All of the flashing is 32 ounce lead covered copper.

The roofs of the office wings are of reinforced concrete slab design. The underside of the slab was utilized as the finished ceiling of the offices below. The west wing roof was finished in red quarry tile in order to make a promenade deck.

Windows

Steel sash was used throughout. The sizes selected are as follows:

1. The sash in the first, second and third floors of the main structure are large units spaced on 10 foot centers. These units are approximately 6 feet high by 7 feet wide, with a single casement opening approximately 18 inches by 54 inches in size.

2. The sash in the office wings are symmetrical units approximately 3 feet wide by 7 feet high, spaced 4 foot 2 inches on centers and with alternate windows as casements. The space between the sash is spanned on the exterior with a concave mullion, and on the interior is boxed in with wall lining material. This space is used to advantage for either structural columns or mechanical services.

3. The basement or service floor sash units are symmetrical, approximately 2'6" by 6'0" in size, and are continuous with every alternate unit as a casement.

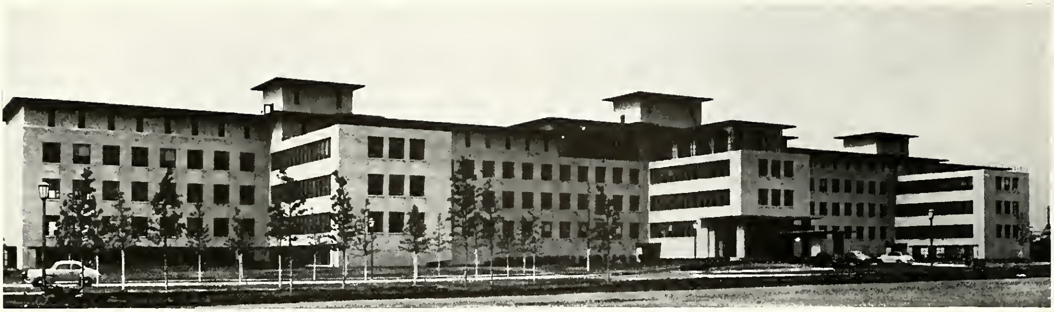


Figure IV.71 The new Research Building, Standard Oil Development Co., Linden, New Jersey.

4. The fourth floor sashes are approximately 2 feet wide by 7 feet 6 inches high. They, too, are spaced 10 feet on centers. These units are composed of two lights of glass, the lower being a casement.
5. In the reception room, library stack rooms, and reading room, the sash is continuous and the full height of the room. This continuous glazing is made up of units of "Thermopane" glass not larger than 3'0" by 4'0". Less than 10% of the gross glass area in these rooms is ventilated. In all cases, the ventilating units are casements one or two panes high.

In special air conditioned laboratories, "Thermopane" was used instead of the plate or double strength glass.

The window hardware used throughout is the crank rotary type in solid bronze. Larger casements like those in the library area use bronze "Simplex" hardware and friction type hinges. All of the other hinges are of steel of the extension cleaning type.

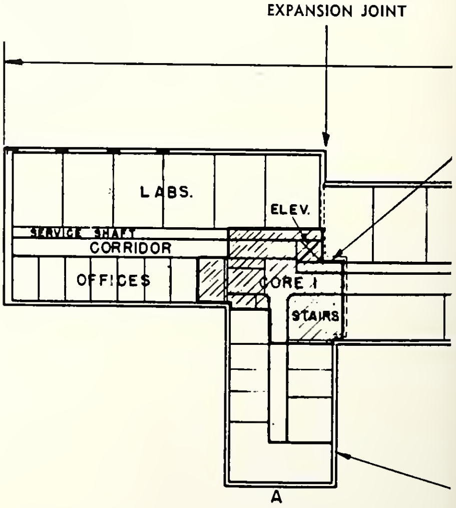
Screens are placed over openings in non-air-conditioned areas such as the service and fourth floors. The service floor window screens are the shading type, and the fourth floor screens are the normal bronze alloy wire type. Window cleaner hooks of bronze are used, and in the full height installations, rails as well are provided.

Structural Steel

As indicated by figure IV.72, conventional steel framing was used. The girders framing into the exterior columns act as supports for 10 foot span reinforced concrete floor slabs. The central supporting columns are offset 2 feet 8 inches to allow services to pass through the module center line, and instead of one center column being used, two angles spaced at 2 feet 10 inches were selected. This permitted an opening on all floors for the service shaft carrying the vertical lines and ducts up through the building, as shown on figure IV.72.

In the office wings, the framing is not as regular and the floor slab spans vary from 7 feet 6 inches to 8 feet 6 inches. Wind bracing consisted of moment connections to the columns. Girder depths were kept uniform to maintain a uniform ceiling construction.

The support of the main curtain walls is divided between spandrel beams and foundation walls. At the



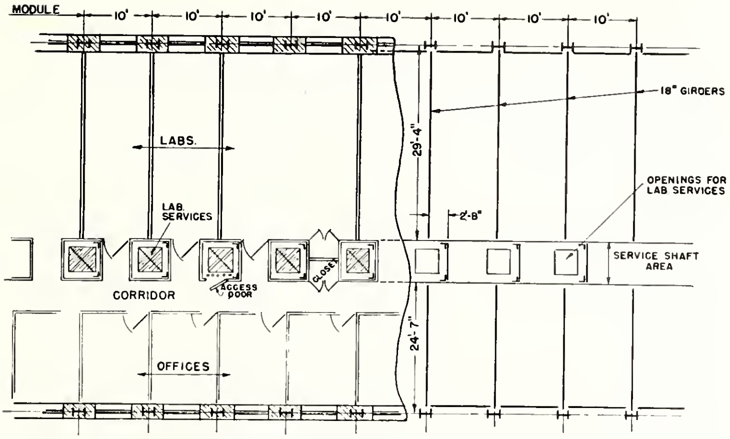


Figure IV.72 Typical floor plan (main structure).

two expansion joint lines there is a distinct separation in the structural steel. Each section is a self-supporting structure. The structural steel design stress used was 20,000 pounds/square inch.

Fireproofing

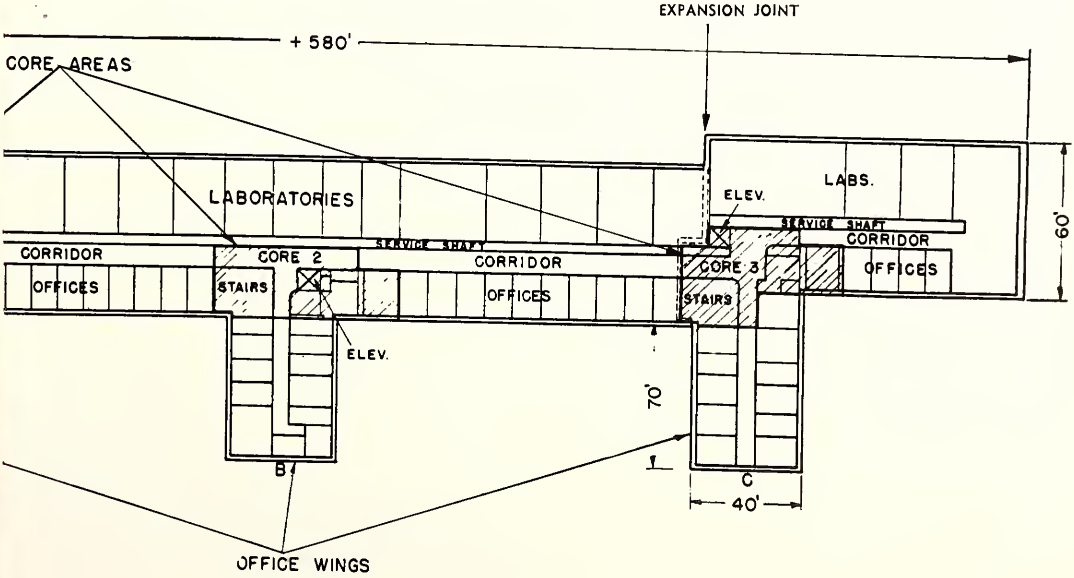
The entire structural steel frame, except for secondary roof beams, was fireproofed with 2 inches of concrete. This concrete was poured in forms in place.

Floors

The floors are of reinforced concrete varying in span from 7 foot 6 inches in the office wings to 10 feet in the main structure. The reinforcing steel was welded wire mesh, and the concrete a class "C" 2500 pounds/square inch mix.

The floor itself is composed of two parts poured at different times. First, the rough slab varying in thickness from 4 inches to 5½ inches and then the fill and

Figure IV.73 Typical floor plan of main floors.



finish adding 2½ inches to 6 inches. Some of the reasons for the 6 inch fill in the laboratory area as illustrated by figure IV.74 are:

1. This space is needed for the installation of large pipe trenches, underfloor duct, and electrical conduit within the floor slab without weakening the supporting slab.
2. The fill can be torn up without impairing the strength of the floor, and the pipe trench, conduit, etc., relocated.
3. The supporting slab can be poured quickly without involving many trades; no special finish is required.
4. As soon as this floor sets, it can be used for traffic and the installation of the trenches and ducts. No significant harm is done if the surface is scarred by dropped tools, etc.
5. The final fill and finish can be installed after all of the heavy work is done and the building enclosed. This is an important consideration if the work is being done in cold weather.

The floors were designed for the following live loads:

First, second and third floors of main structure	100	pounds/square foot
Office wings	50	" " "
Reception room	100	" " "
Auditorium	100	" " "
Fourth storage areas	200	" " "
Library stack rooms (two tier areas)	250	" " "
Library reading room	100	" " "
Stair wells and corridors	100	" " "
Roof	40	" " "
Other storage areas	150 and 200	" " "

Wearing Surfaces on Floors

In the laboratories, offices, and corridors, a resilient asphalt tile 3/16 inches thick and in 12 inch squares was used. The use of the 12 inch square worked out very well with the modular spacing and has proven very helpful for the occupants in visualizing dimensions for location of furniture and equipment.

Other floor surfaces used were as follows:

A. "Alberene" or blue stone for the reception room. (The reason for the selection of an outdoor material was to help cushion the abrupt transition between outdoors and indoors; the choice of full height "Thermopane" glass also helped in this respect.)
B. Terrazzo for the stair wells.
C. Cork for the conference rooms and part of the auditorium floor.
D. Carpeting for the aisles and front area of the auditorium, and for the preview theater.
E. Ceramic tile for the lavatories.

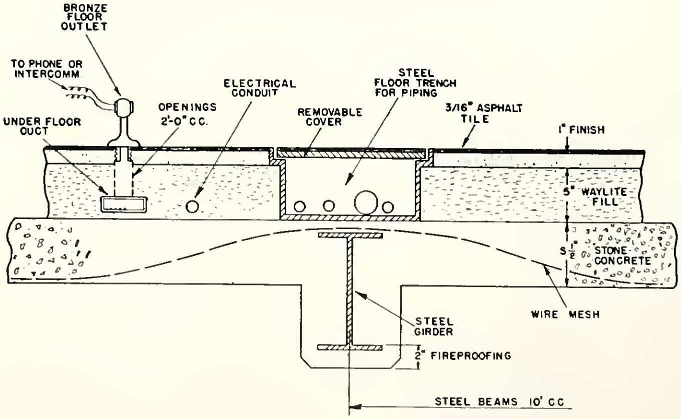
Stairs

As shown in figure IV.73, there are three stair wells in the building, each approximately 20 feet by 16 feet, with 5 foot wide stairs. A gentle slope using a 6¾ inch riser by 13 inch tread was used and has proven very satisfactory. The stair treads, as well as landings, are of terrazzo. All the exterior stairs, on the other hand, are of "Alberene" stone.

Ceilings

Except for special cases, all of the laboratory and office ceilings are the exposed concrete floor slabs of the floor above, so special care was taken in forming

Figure IV.74 Typical laboratory floor section.



these floors. Plywood forms, symmetrically placed, were used, and after stripping, the exposed concrete was rubbed and touched up where necessary. Three coats of flat while paint were required to do a satisfactory job.

The ceilings in the corridors and conference rooms are hung perforated metal pans embossed in a 12" by 12" pattern backed with inorganic sound proofing.

In some of the offices, typists' rooms, and the lunch room, 12 inch squares of one inch thick perforated soundproof material cemented to the underside of the concrete slabs was used.

Partitions

Metal partitions and metal wall linings are used throughout the building except in the core areas, service floor, fourth floor, auditorium area and reception room. The partitions are 3 inches thick, with faces of 20 gauge steel, packed solid with an inorganic filler and are factory finished in a buff eggshell baked on enamel. Standard panels are used for these partitions and are in widths up to 48 inches. Installed with a cap, the total height of the partition comes to 9 feet 2½ inches; and since all clear floor heights are over 10 feet, a filler piece, made up of double mineral board packed with rock wool, is used. This provision makes it easy to scribe to an uneven ceiling. The filler piece is painted to match either the ceiling or partition as dictated by location.

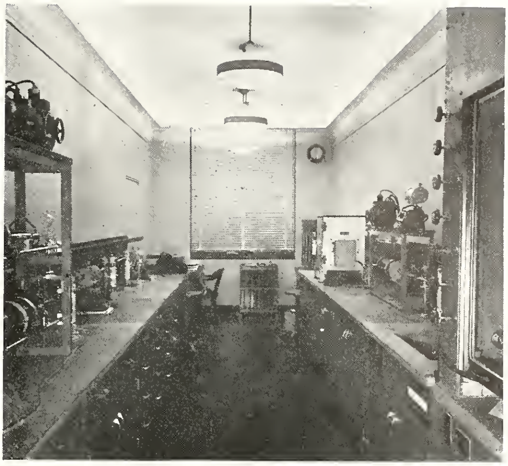
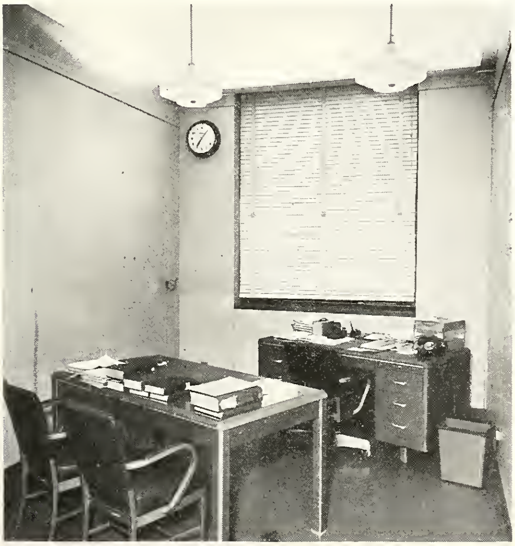


Figure IV.75 Typical 10-foot laboratory.

Figure IV.76 Typical 10-foot office room in main structure with plain painted ceiling.



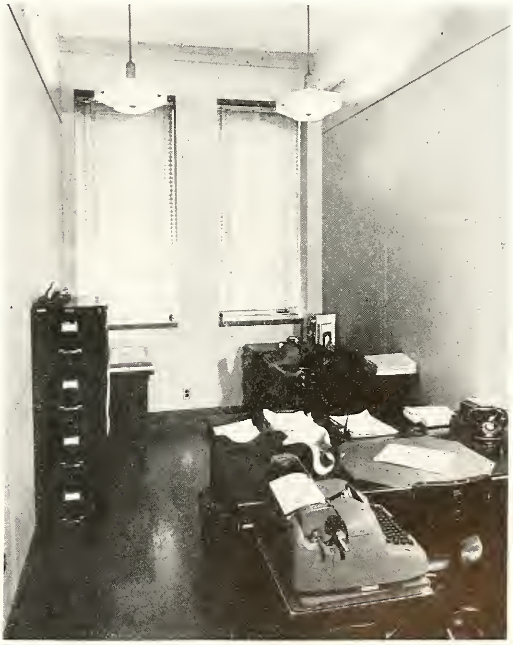


Figure IV.77 Typical 8'4" room in office wing with acoustic ceiling treatment.

The partitions are so constructed that it is possible to run "BX" cable hidden in the base or top filler and behind post caps to receptacle boxes at any height above the floor. The post caps are the connecting pieces between adjoining panels and occur at every joint.

Plaster finished partitions are used in the service floor and the core areas. The partitions are made up of hollow tile structural blocks with the usual scratch, brown and white finish coats. The finished wall was painted to match the metal partitions.

Air Conditioning

Except for certain areas described below, the bulk of the offices and laboratories are conditioned with a one-way system. Since the odors emanating from the laboratories may be objectionable, it was decided not to recirculate air. Ten air changes per hour was the design basis for the laboratories and five for the offices.

The outside air is drawn in through louvers in the side of the building at the service floor level. The air then passes through a continuous oil filter, preheater coil, cooling coil, reheater coil and through the blower up the main ducts to the outlets located near the ceilings in the rooms.

The amount of air drawn into the building and conditioned is calculated to be in excess of that withdrawn from the building, so that the building is under a slight positive pressure. This creates leaks out of the building, rather than in, at any openings such as windows, doors, etc. The spent air is withdrawn through the fume hoods, thus supplying continual ventilation of these hoods. The flow of air is illustrated in figure IV.78.

In winter the heater coils, heated with thermostatically controlled low pressure steam, warm the air to the desired temperature. Spray nozzles add moisture to the air if necessary.

In hot weather heater coils are dormant and cooling coils, chilled with 50°F water, cool the air to the desired temperature. By-pass valves controlled by thermostats divert the chilled water from the coils, thus maintaining the desired air temperature.

The air conditioning controls for any particular unit consist of thermostats in specific zones at each floor. These thermostats transmit their impulses to an averaging relay which controls the air temperature only.

The air conditioning equipment controls, such as for dampers, valves, etc., are the pneumatic type operating on air at 15 psi.

Steam heated fin type radiators at each window augment the air conditioning system in winter and are manually controlled.

Special Laboratory Air Conditioning

In some of the laboratories, the humidity has to be controlled to within 2%. In these cases, "Kathabar" chemical dehumidifier units are used in addition to the usual filter, heater, and cooling coils. The air in these special laboratories is re-circulated with calculated additions of fresh air. Since these systems operate independently, they are equipped with individual compressors.

Conference Room Air Conditioning

The conference rooms have their own air conditioning systems which include electrostatic precipitators, capable of removing dust, pollen, and smoke from the air. These systems recirculate the air and utilize building chilled water.

Figure IV.78 Diagram showing the flow of conditioned air through the laboratories and offices.

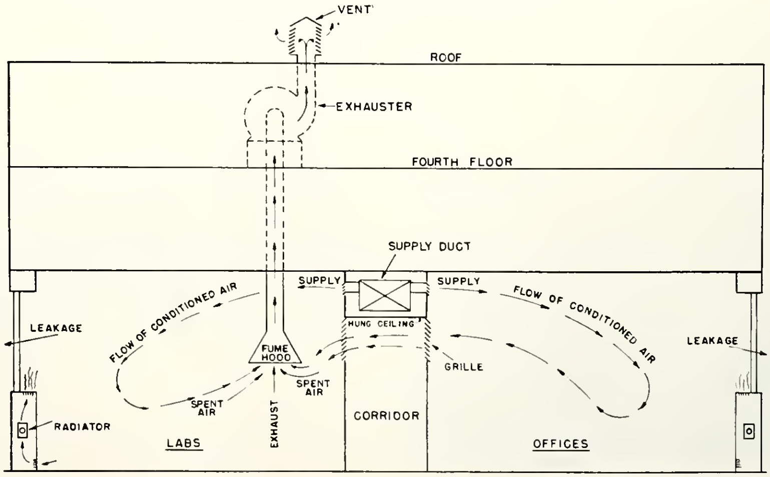
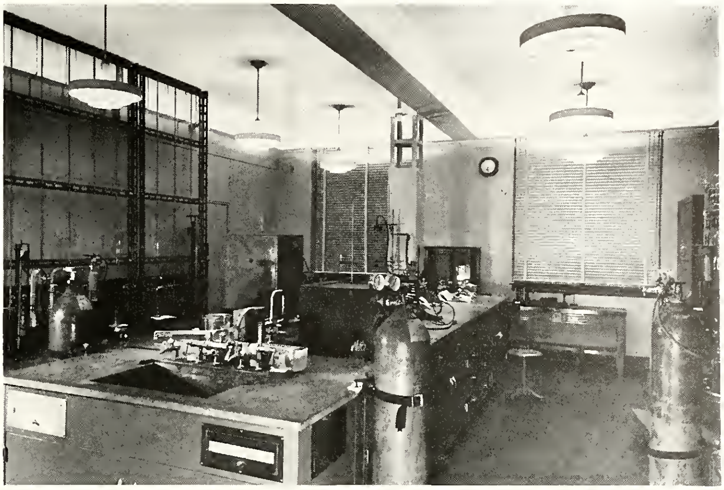


Figure IV.79 Typical 20-foot wide laboratory with island bench installation.

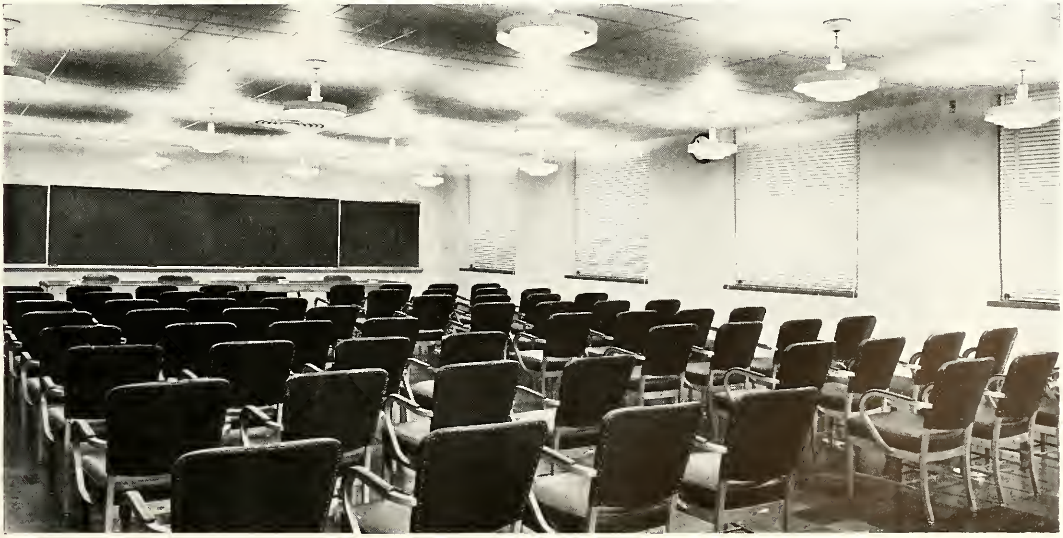


Mechanical Services

Steam (120 psi) is piped in underground lines from the boiler house at nearby Bayway refinery. After entering the building at the service floor, it is reduced in two stages to 15 psi and distributed. For special laboratories, a steam booster compressor raises the incoming steam from 120 pounds to 225 pounds/square inch.

Electricity at 6900 volts, 3 phase, is brought by underground cable from the Bayway refinery to a substation within the grounds. Here it is transformed to 4160 volts, 3 phase, and goes through underground ducts to the service floor of the building to two load centers. At these points, it is transformed and distributed by bus duct and conduit to risers in service shafts and eventually to laboratory tables and other points of use. The services are 3 phase, 4 wire, 120-208 volts, and 440 volts.

Figure IV.80 View of small 75-man conference room, showing ceilings of soundproof perforated metal pans and floor covering of cork.



Vacuum. Two vacuum pumps located in an equipment room on the service floor provide all of the laboratory vacuum needs. An aspirating strength equivalent to 22 inches of mercury is maintained. The pumps are automatically controlled so that when the vacuum in the storage tank drops to 20 inches the pumps start, and when 27 inches is reached, they stop.

Compressed Air. Two piston-type compressors located in an adjacent motor laboratory building provide compressed air at 120 psi pressure. The air is piped to the service floor through underground lines, reduced and distributed. Air at 15 psi is used by the pneumatic controls and at 30 psi by the laboratories.

Laboratory bench chilled water is supplied at approximately 50°F by piston type compressors located on the service floor.

Building chilled water (45°-48°F) for air conditioning of the offices and laboratories is supplied by two 500 hp, 500 ton centrifugal type, water-cooled compressors. These machines operate in summer only.

Chilled water for special air conditioning systems is supplied by piston type compressors independent of the above systems.

Cooling Tower. Treated water for condensers, compressors, and other machines is cooled by a 5000 gallons/minute, 4 cell, induced draft, redwood cooling tower, located on the grounds nearby. This tower is rated to cool water from 95° to 85° at 78°F wet bulb.

Hot Water. Hot water is provided by a steam hot water heater located on the service floor.

Distilled Water. A steam heated still, located in the central penthouse, makes and stores in adjacent tanks approximately 600 gallons of distilled water. The still is of stainless steel, and the distributing lines are of aluminum.

Water—Potable and process city water at the point of entry is divided into two services, potable and process. This is an anti-pollution measure.

Fuel gas is brought into the service floor via underground line, through meters and to the service shafts. At each laboratory connection in the service shaft, accessible quick-acting shut-off valves are provided. Riser and laboratory lines are soldered streamline copper tubing.

Provisions are made in special laboratories for storing and piping special gases like hydrogen, nitrogen, oxygen and certain liquids.

Lighting

The lighting used is chiefly the incandescent type. However, fluorescent lights are used in certain areas such as shops and store rooms where space limitations dictate that type of fixture.

Utility Rooms

Utility or equipment rooms, of which there are six, are located on the service floor spaced throughout the length of the building and under the office wings. Each room contains air conditioning equipment to handle a

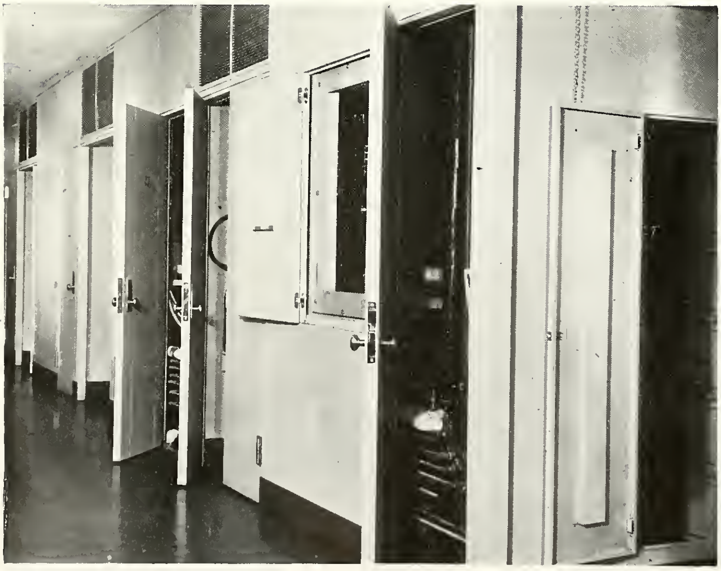


Figure IV.81 View from corridor shows access doors to service shaft, valved connections to risers, electrical panels, and grilles over the door for flow of spent conditioned air.

portion of the building, and other mechanical units, such as chilled water compressors, steam booster compressor, vacuum pumps, drinking water filters and coolers, hot water heater, etc.

The water and gas meters are located in separate rooms near the point of entry of these services.

Utility Piping

Rigid type "K" copper tubing with streamline soldered fittings is used extensively in the building.

Black iron pipe with screwed fittings is used for steam, and aluminum pipe with screwed aluminum fittings is used for distilled water.

All of the services emanating from the different equipment rooms run along the length of the service floor corridor or along the top of the service shafts on the fourth floor and at every 10 feet, connections are made to the risers in the service shafts. The risers range in size from ½ inch to 1 inch in diameter, and at each floor, valved connections are made to these risers for the services to the laboratories.

Laboratory Piping

Installed at the back of each laboratory table is a self-supporting service strip on which are mounted the various fittings and electrical pedestals. This strip is approximately 6 inches wide, is of black enameled birch, and is about 1 inch higher than the table top. For wall installations, the strip has a regular splash back, and for island tables it is flat topped. The laboratory fittings dispensing the various services are repeated in groups every 64 inches. Connections to the fittings are made on the underside of the service strip.

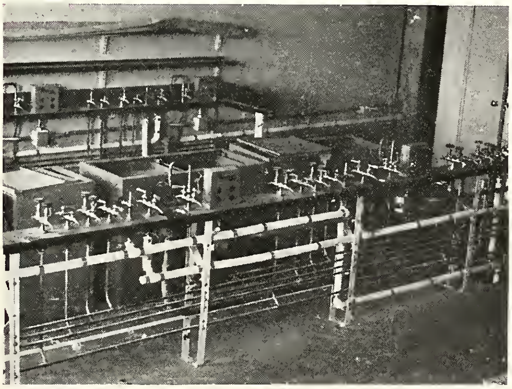
The fittings are piped to the risers in the service shaft in two ways: 1. in wall table installations the piping goes direct to the service shaft; 2. in island table installations the lines drop into a floor trench connecting to the service shaft.

The laboratory fittings are of brass, and are conventional in every respect except that the dispensing nozzles are serrated tips bent down 22½° from the horizontal. The connecting pipes are ½ inch diameter hard "K" copper tubing, the steam and chilled water lines being insulated. The cold water fixtures are fitted with goose necks and lead drain cups. These drain cups are ¼ inch thick chemical lead, oval in shape, and drain through lead traps to cast iron drainage lines in the service shaft. Each lead trap is equipped with a bottom clean-out plug that has a cavity to intercept spilled mercury.

Special electrical pedestals, single-faced for wall, and double-faced for island installations, are part of the group of laboratory services. Each face of the pedestal is equipped with four 4-pronged outlets protected with two twenty-ampere circuit breakers. Each of the outlets dispenses 120 volts single phase.

The laboratory tables are of steel, with "Alberene" stone tops, and are pushed up against the service strips, completely hiding the piping. For piping maintenance, the table is pulled back and all of the pipes and electrical conduits are exposed.

Figure IV.82 This view of a laboratory during construction shows wall and island bench service strips in place.



Telephone and Buzzer Ducts

In addition to the conventional conduit installed in walls, special underfloor ducts were also installed (see figure IV.74). This duct is rectangular in shape and has available openings to the surface of the floor every two feet. Normally, the openings are capped, flush with the cement floor, and are hidden by the asphalt tile. In every room, a bronze flat-headed screw, flush with the asphalt tile, is set over one of the openings, giving the location of the duct, and by measuring in 2 foot increments, an outlet can easily be located and cut through. It is also possible, using a special rotary saw, to cut into the duct at any other point. Special fittings are available to bring wires above the floor for island desk locations.

Lavatories and Rest Rooms

Lavatories are located on all floors except the fourth, and there is a total of twelve men's rooms and seven women's rooms in the building. Each women's room has an adjoining rest room.

Cafeteria

The cafeteria, capable of seating 250 people, is located on the fourth floor. Ceilings are of 1 inch thick perforated soundproof material, the floor covered with asphalt tile, and the inside walls are painted cinder block. The windows are "Thermopane" and continuous, and are hung with drapes. Radiator enclosures below the windows are of natural birch paneling. This area is served by a separate air conditioning unit, which, re-circulates part of the air and utilizes building chilled water.

Auditorium

The auditorium, large enough to seat 120 people in fixed seats and 30 additional in moveable seats, is located on the first floor close to the main entrance. The walls and ceiling are paneled in oak. The floor directly under the tiered fixed seats is covered with cork, the aisles and remaining floor area with padded carpeting. Since the entire room was designed with particular attention to acoustics, the paneling was curved to diffuse sound. It is possible to talk from any point in the auditorium and be heard without amplification. Thus, audience discussions are possible. The auditorium has a modern fireproofed sound motion picture projection room that can project 35-mm movie film, although 16-mm is generally used.

The film is projected on a screen, approximately 7'3" by 9'6", which can be hidden by motor-driven curtains. Large sliding panels with blackboards on the lower half can be moved in front of the curtains. On both sides of the screen, covered by vertically sliding panels, are additional blackboards. Altogether, approximately 90 square feet of blackboard area can be exposed.

The entire auditorium is illuminated by concealed lighting fixtures which can be dimmed from the projection room. The blackboards are illuminated by concealed fluorescent and "baby spot" lights.

Located in the back of the auditorium are two entrances and cloak rooms, also a sound-proofed phone room.

Recording Room

Located to one side of the auditorium is a recording room. This room has double glazed windows opening into the auditorium and into a preview theater. An operator in this room can observe the occupants in the auditorium or preview theater and can record their voices. These windows can be closed with curtains.

Preview Theater and Recording Studio

This is a smaller version of the auditorium and is similar in decor; in addition it has a sound-proof floating concrete floor. In this small theater it is possible to preview films, add sound track and make ordinary recordings with a minimum of extraneous noises.

Main Entrance and Reception Room

The main entrance is reached by a sweeping curved driveway. A large canopy with prominent overhangs projects out beyond the building line over the driveway, sheltering the main entrance and any car discharging passengers. The canopy is a structural steel and gypsum plank frame, covered with lead-covered copper roofing, with exposed edges of "Monel" metal. The underside of lacewood paneling is varnished to a satin finish. The columns supporting the canopy are rectangular in cross section, and are clad in enameled steel colored to match the brick of the building. The sidewalks and steps in this area are of "Alberene" stone.

The entrance to the reception room is through a bronze revolving door flanked by two conventional doors. The reception room is a large room with a 16 foot ceiling and three walls of "Thermopane" glass extending from floor to ceiling. The windows are hung with full length drapes. The ceiling and interior walls are lacewood panels lacquered to a satin finish. The floor is of "Alberene" stone. The room is lighted by concealed ceiling fixtures. All of the furniture, including the receptionist's desk, is of oak in modern design. Since the reception room is slightly lower than the first floor, a two-sided stairway, shielded by a heavy plate glass windbreak, leads to the corridor beyond.

Library

The library contains 25,000 volumes and is housed in a special area on the fourth floor. This area is broken up into two stack rooms of a total floor size of about 24'0" by 140'0", two tiers high, and a 32'0" by 50'0" reading room. All of the windows in the library and reading room areas are "Thermopane" extending to the ceiling. The two-tiered self-supporting steel book stacks are essentially independent of the building structural steel.

Fire Alarm System

Even though the building itself is of fireproof construction, many of the materials used and stored are combustible. Therefore, it was found necessary to install an elaborate fire alarm system. Spaced out on each floor are three pull-type fire alarm boxes which connect simultaneously to a ticker-tape recorder at the gate house on the grounds, to fire alarm bells, to the city fire department, and to all of the electro-magnetic door catches in the stair wells. When an alarm is pulled, all of the stair well doors are released and automatically close (but do not lock), an alarm bell rings the code number for the building, and after a pause, the code for the location. At the gate house, each ring is recorded on a tape so that the exact location will be known. The building is also well equipped with CO_2 cylinder fire extinguishers and fire hose cabinets with hose long enough to reach any part of the building.

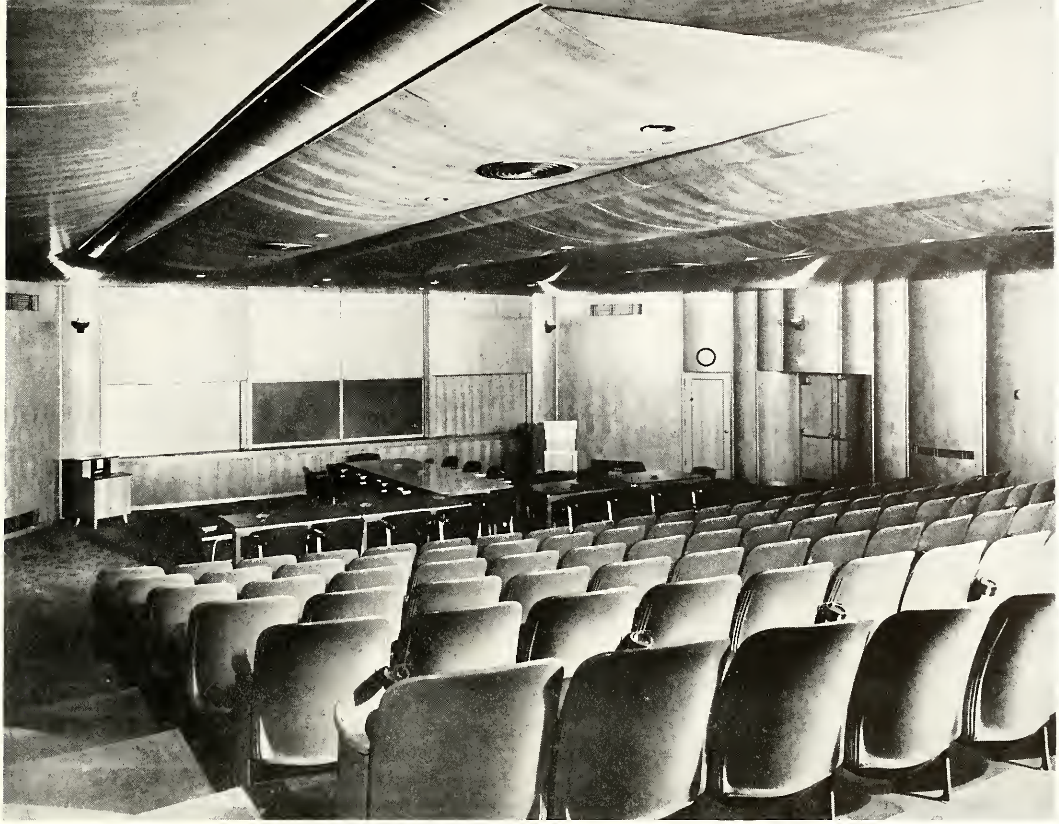


Figure IV.83 Front view of auditorium shows curved panel wall and ceiling construction, light openings, blackboards, and sliding panels behind which motion picture screen is hung.

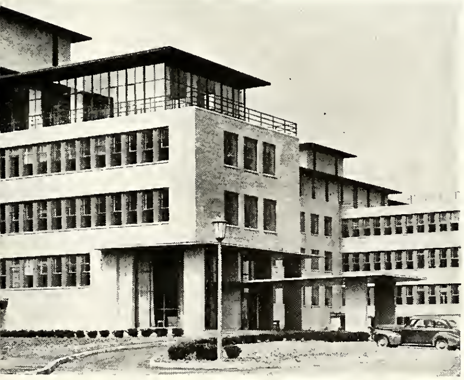
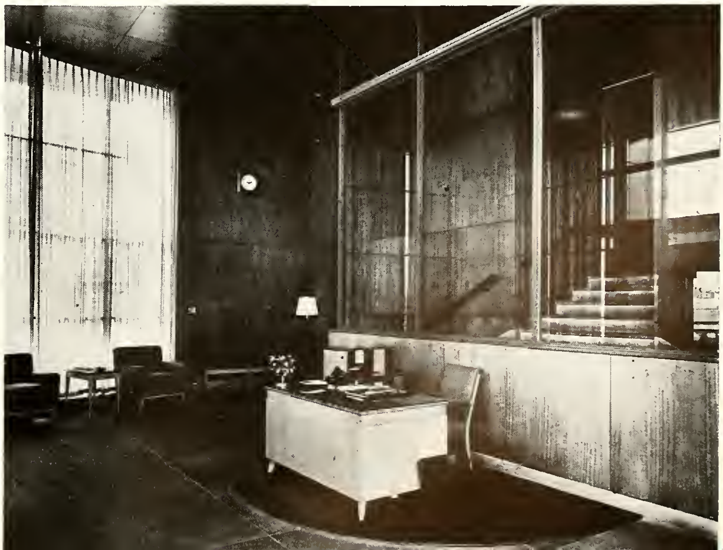


Figure IV.84 (Left) Main entrance to the new Research Building.

Figure IV.85 (Right) View of the reception room which shows the stairway leading to the main corridor.



11

B. F. GOODRICH RESEARCH CENTER

D. H. Cornell

The B. F. Goodrich Co., Brecksville, Ohio

On June 15, 1948, an inaugural ceremony was held at the new B. F. Goodrich Research Center. This meeting marked the completion of many years of planning by Goodrich personnel and their architect, William M. Stanton, and two years of actual construction which resulted in a new home for research activities. The modest ceremony was attended only by B. F. Goodrich employees. They witnessed the dedication and toured a laboratory which embodies an assemblage of ideas from many individuals. One must know and understand some of the basic policies and requirements for these buildings to appreciate the design of the facilities.

It was the desire of the company management to effect the physical separation of the Research Division from the factory development departments. Experience had shown that it is difficult for a group of scientists to make progress on fundamental research programs if they are continually interrupted in favor of "trouble shooting" problems. This is in no way intended to minimize the need or importance of development groups. Product development, production techniques and control testing are vital components of any industrial organization. As a corporation matures and increases in size it becomes more advantageous to consign the responsibilities to specialists. On the other hand, industrial research must discover information that ultimately increases the revenue of its sponsor. True research is insurance for the future, and current investments may not be realized until years have elapsed, allowing development and production groups to offer the public new articles resulting from research discoveries.

A well-equipped, self-sustaining unit was to be erected. The buildings were to be free of noise and vibration. They were to be architecturally attractive, and designed for location in a cultural neighborhood. An initial set of plans was drawn and submitted to contractors for bids. The estimates received were so high that it was necessary to abandon the plans. These were indeed dark days for the planners of the new laboratory. It was realized that with rising building costs nothing less than a unique design could reduce the cost to an amount that would be acceptable to the management without reducing minimum laboratory requirements. It was at this point that William M. Stanton, an architect who had been doing a very creditable job for the company on war plants, devised a new general plan which would meet the requirements of the basic policy. It should also be stated that Mr. Stanton not only directed the detailed design of his new general plan for the B. F. Goodrich Research Center but he also served as project manager throughout the entire construction period. It is a wise decision to retain the chief designer of a project as an active member of the construction supervision staff. Whenever questions arise during construction there is a capable man available to make decisions who is completely familiar with the history of the project.

BASIC PLAN

In the new plan, the main laboratory was to be designed on a modular system. The modules or units were to be grouped or separated to satisfy the requirements of the 10 separate research departments. Special facilities were to be provided to establish the research division as a self-sustaining unit. Within practical limits, all service functions for research were to be performed at the Research Center. These would include personnel, purchasing, library, cafeteria, testing, engineering, maintenance, protection, etc. Properly conditioned air was to be supplied to the laboratories for uniform testing conditions, and adequate lighting was to be provided for proper working conditions. Every advantage was to be realized from a windowless

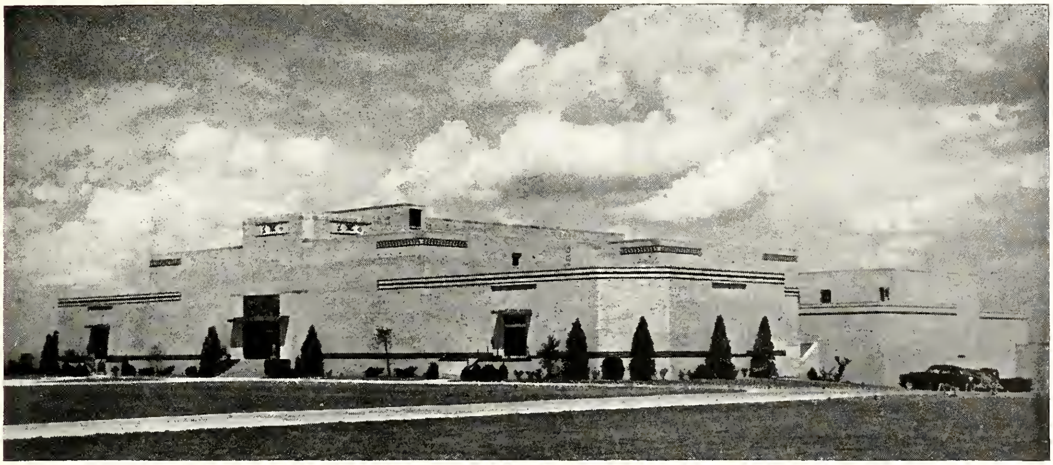


Figure IV.86 B. F. Goodrich Research Center, Brecksville, Ohio.

design to reduce costs so that the project could be reconsidered. In order to segregate vibration-free areas, two 3-story buildings were to be erected—one (without vibration) to serve as a main research laboratory, the other to be devoted to engineering research and services. Three smaller buildings were to be erected to isolate the dangers involved in their respective functions. They were to be specially constructed with safety devices to accommodate work involving highly toxic gases, work at high pressures and the storage of solvents in drum quantities, respectively. Proper consideration was to be given to the architecture and landscaping to make the center a credit to its company and the community in which it is located. The description which follows is actually an explanation of the methods used to apply this general plan.

SITE

A 314-acre site in Brecksville, Ohio, was chosen from a long list of suggested locations because it more nearly satisfied basic requirements than any other plot. The community is non-industrial and provides a natural setting for beautiful buildings. Vibration requirements are satisfied because the site is over a mile from the nearest railroad and its area is large enough to permit the buildings to be located beyond the range of vibrations from the nearest public highways. Although the Research Center is removed from all industrial plants, it is less than twenty miles from the general offices of the B. F. Goodrich Company in Akron and the B. F. Goodrich Chemical Company in Cleveland. Adequate utilities were available including electricity, gas, sewer and water. Since Lake Erie is the source of the water supply, a relatively constant hardness is assured.

BASIC MODULE

The main research laboratory, with the exception of its two wings, is constituted from basic modules, or repetitive space units. Each unit is 10 feet by 26 feet in area and 10 feet high. The standard services to each module are hot and cold water, drain, natural gas, compressed air and 110 volt electric power. Available in all units and installed where desired are distilled water, 50 psi steam, 220 volt single phase electric power, 440 volt 3 phase electric power and a fume hood. Initially 72 modules of a possible 104 modules are equipped as laboratories. The remaining modules are devoted to offices, stock room or other service functions. Figures IV.87 and IV.88 describe the module. Figure IV.87 is a plan of two typical adjacent modules. Figure IV.88 is an illustration of a multi-module laboratory room.

In modern laboratories, the modular system has been found most convenient where flexibility in design is required. It is not necessary to place partitions between the modules. At the B. F. Goodrich Research Center, laboratory rooms always have the 26 foot dimension perpendicular to the corridor. The other dimension of the room, parallel to the corridor, is 10 feet or any multiple thereof up to limits determined by the outside walls of the building. All pipe bands are complete and provided with capped tees whether or not the laboratory services are initially installed in the rooms. All internal walls are movable metal partitions, so that additions or changes in the rooms can be made at any time without seriously disturbing the fundamental system. The floor tile was laid before any metal partitions were erected. This makes it possible to add or remove partitions without leaving any scars resulting from mismatched floor tile. (Obviously this flexibility does not apply to the tile walls around toilet rooms, star wells, elevator shafts and fire walls required by code.)

Figure IV.89 is a plan view of the second or middle floor of the main research laboratory and illustrates the relative arrangements of laboratory modules in the basic structure. The main entrance or lobby is on the middle floor. Receding grade lines partially submerge the first floor at the front of the building only. The two main corridors are parallel to the front of the building. Pipe bands with utility services are along the front, the rear walls and through the center line of the building. The left and right wings house the library and auditorium respectively. A stair well, a pipe shaft and an elevator shaft are adjacent in the center of the building.

BASIC STRUCTURE FOR MAIN RESEARCH LABORATORY BUILDING

The main research laboratory building was designed especially to accommodate the module system described above. A typical elevation section is shown in figure IV.90. This section is taken through modules and corridors on two floors. On the left-hand side is shown an outside wall and the pipe bands. It will be noted that the weight of the outside brick wall is supported on a spandrel beam approximately 4 feet above the floor slab. This makes it possible to reduce the outside wall thickness below the beam to the floor slab level so as to provide space for the pipe band. All services are supplied to the laboratory from the outside wall. The space between the columns is used for auxiliary hood air supply and exhaust ducts. These supply and exhaust ducts extend from a low ceiling service floor above the building down one, two or three floors as required. A close examination of the space between the outer walls and the metal furring will reveal that a large portion of this space is occupied by pipe, conduit or air conditioning ducts. Such a compact arrangement produces an economical design.

The corridor is 6'0" wide by 8'6" high. All doors from the units open into the corridor, and they are equipped with door closers and roller latches for smooth operation. Above the corridor ceilings are several services such as conditioned air supplies, steam, condensate, booster heaters, electric wires for corridor lights, instrument air for air conditioning controls, water for emergency showers, and floor drain pipes for the corridor of the floor above. One-fourth inch thick perforated ceiling tile is screwed to metal channels. This policy was established for all corridors to facilitate maintenance of the services above the ceilings. A view of a typical corridor is shown in figure IV.91.

All laboratories have white acoustical ceilings and instant-start, recessed fluorescent lights. All ceiling tiles in laboratories are glued and screwed to mineral board. The walls, which are light green, are of the movable metal type. The doors, baseboards and laboratory furniture are finished in a darker green. The floors are marbleized asphalt in two colors of tan and installed in a checkered arrangement on a concrete floor slab. Steel, concrete, brick and stone are used wherever possible. Combustible materials are held to a minimum in both buildings and furnishings.

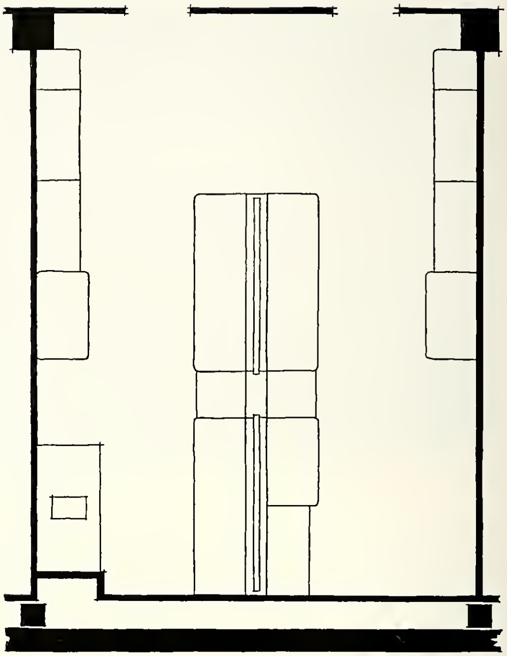


Figure IV.-87 Plan of two typicol adjacent modules.

It has already been mentioned that vibration-free buildings are needed for many types of high-grade research. Elaborate precautions have been taken to isolate the vibration created by all rotating machinery in the main research laboratory by mounting these units on rubber-in-sheer vibration insulators. With these mountings building services or laboratory machinery with rotating parts will not destroy the vibration-free surroundings that are acquired at the Brecksville site. In addition to these precautions, piers extend through the first floor slab to bed rock which is approximately 9 to 15 feet below the floor. The piers, 2'0" by 3'0", in cross section, are made of solid concrete and are completely independent of the building. They are provided as bases for an electron microscope, optical equipment and other delicate apparatus that are particularly sensitive to vibration.

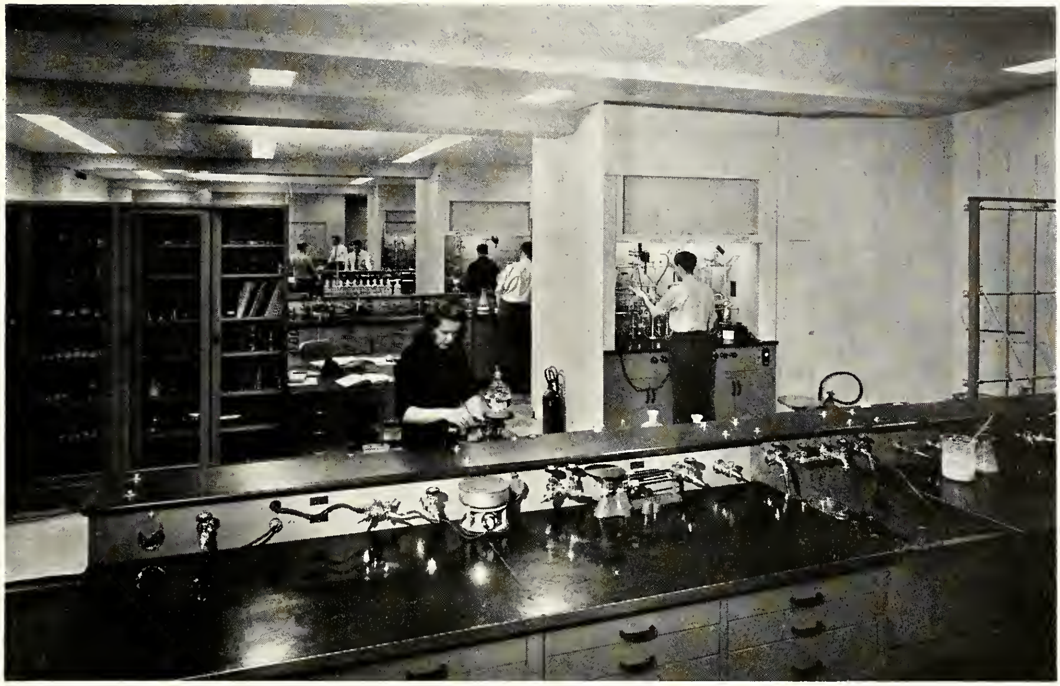
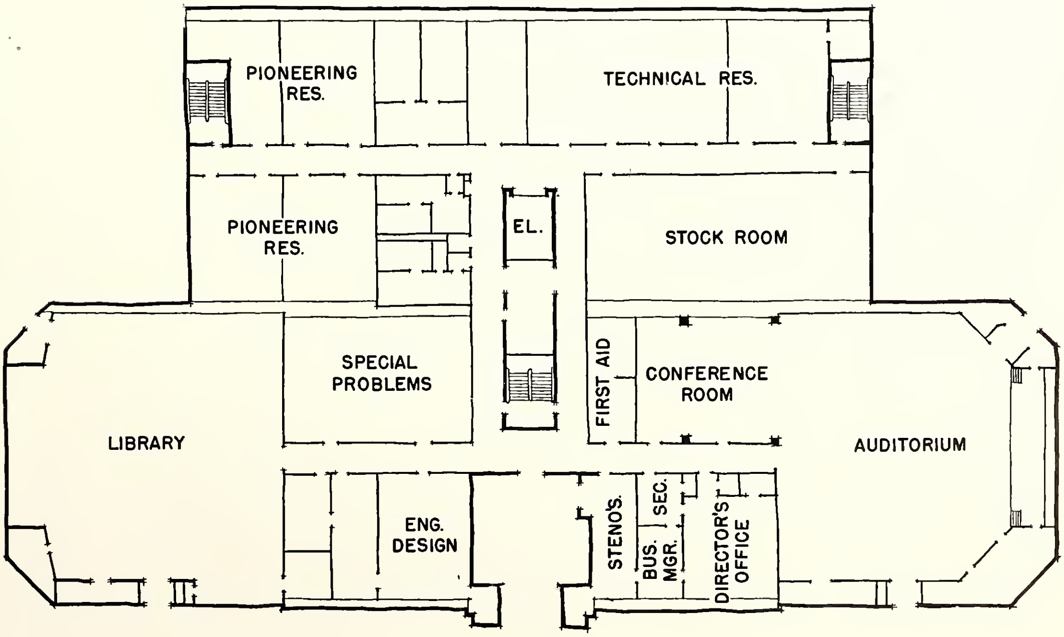


Figure IV.88 A multi-module laboratory.

IV.89 First floor plan.

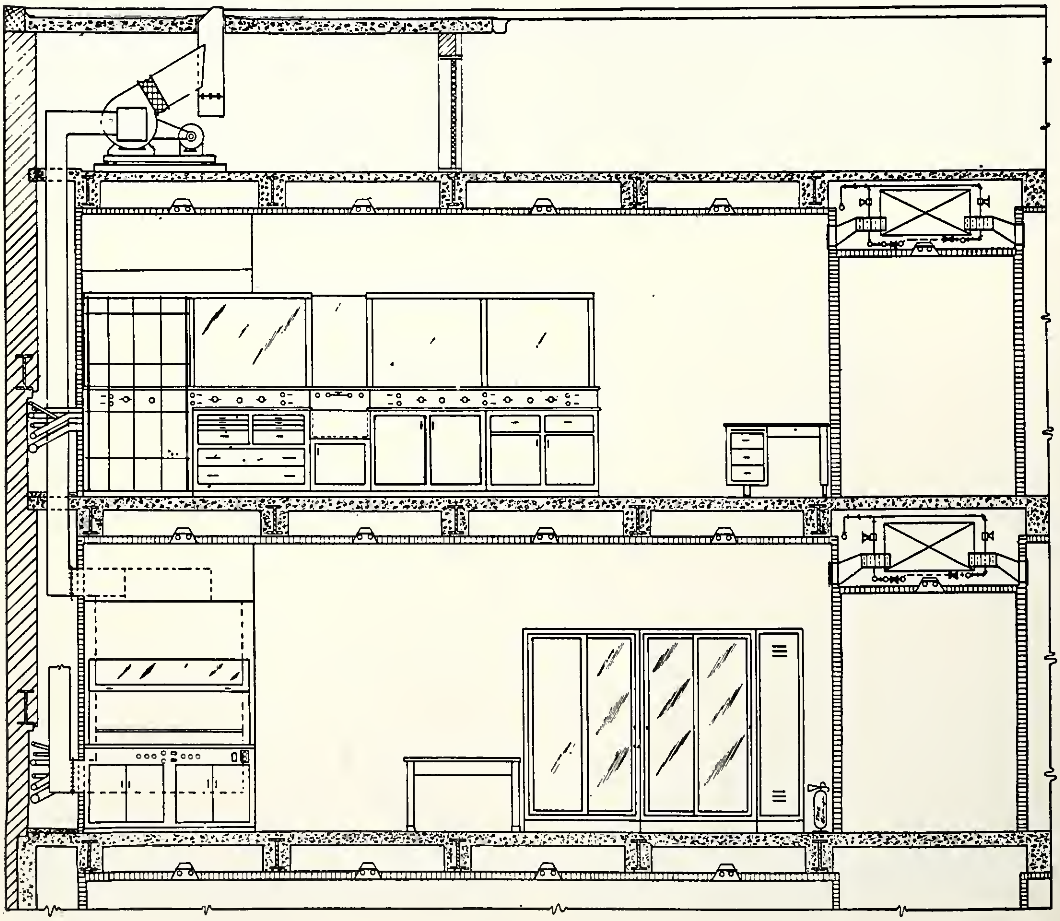


WINDOWLESS DESIGN

It will be recalled that the basic plans required that adequate ventilation and light be supplied to all working areas. If good light and air are supplied, windows will have only psychological value. A detailed analysis showed not only that the windowless design was the radical change necessary to reduce initial costs, but also that this design offered many operational advantages. The walls are virtually lined with pipes and ducts, keeping void space to a minimum. Pipe bands are installed back of metal walls at convenient working heights where they are readily available for maintenance. This system of distributing services completely eliminates sub-floors (which add useless volume and expense to the building) and trenches (which easily collect dirt or water from floor surfaces). The initial expense and maintenance of window sash and blinds are saved. Estimates indicate that there is approximately a 25% saving in operational costs of heating and cooling. This is due to the elimination of heat gains or losses through window infiltration and radiations. The arrangement of furniture and equipment is simplified by uniform distribution of light. It is unnecessary to face desks "north," and the added wall space facilitates the layout of laboratory and office equipment.

It is no small decision for management to invest a large sum of money in research buildings without windows. A careful investigation was made into reactions of laboratory, office and factory workers who were already working in "black-out" or windowless type buildings. It was found that a large majority of workers were pleased with windowless buildings if they were properly designed. It is extremely important that certain important principles are observed. Ade-

Figure IV.90 Typical elevation section.



quate light must be uniformly distributed over the working area. Small rooms should be avoided as much as possible. The use of light colors helps keep the light level high and gives the illusion of larger rooms. Expert illuminating engineers were consulted to assist in the design of the room lighting and in a careful selection of a properly blended color scheme.

AIR CONDITIONING

Air conditioning in a windowless building is essential and must be very carefully designed to insure proper working conditions. Fundamentally, a system has been installed in the main research laboratory which is capable of supplying a volume of air equal to the entire building every 6½ minutes. This is 100% new air, and no recirculated air is used. It is believed that recirculation of air in a laboratory containing a number of

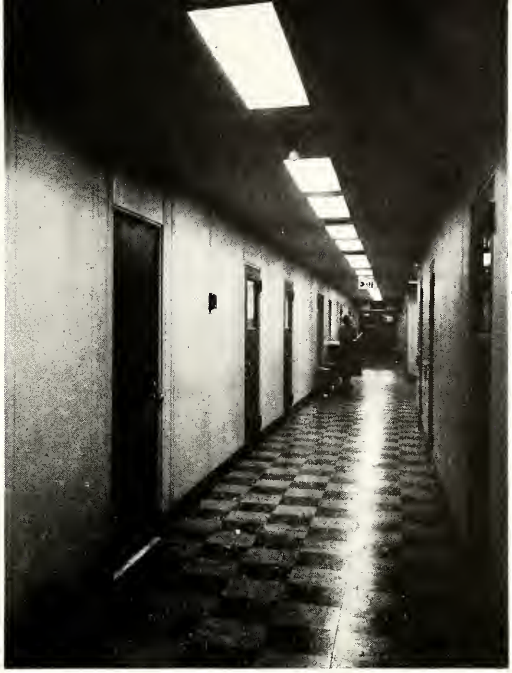
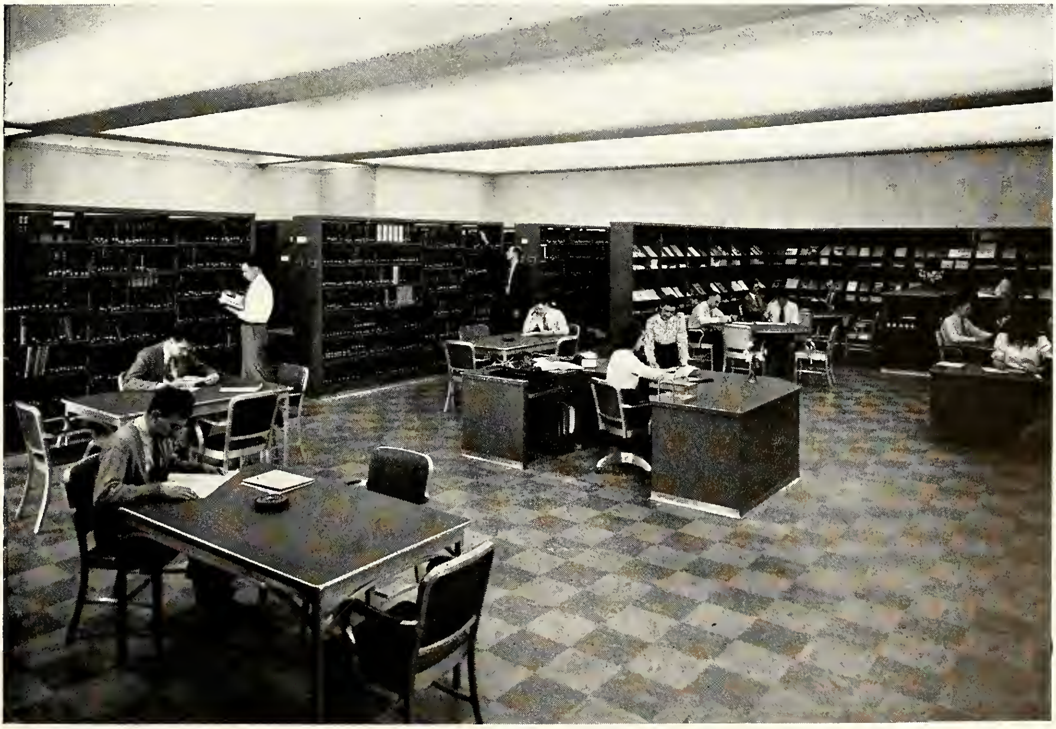


Figure IV.91 A typical corridor.

Figure IV.92 The library. B. F. Goodrich Research Center.



rooms is impractical because of the many odors which are involved.

The second basic provision in the air conditioning system is the installation of an individual thermostat in every room or in every two modules, whichever is smaller. One of the cardinal principles of air conditioning is that one thermostat should control the temperature of the air in one room. The main system conditions the air to 65° dry bulb and a proper humidity. The cycle is established entirely by outside weather conditions. This may mean heating or cooling the air. It might also mean the addition or the precipitation of moisture. The 65° supply air in the main ducts is cool enough to balance the heat gains in any of the laboratories. From figure IV.90 it can be seen that the air is supplied through ducts in the corridor ceiling. The air is then split off at right angles to the main duct through a booster heater and grille to the laboratory room. The booster heater is controlled by the room thermostat so that a suitable ambient room temperature is maintained. The exhaust is then through the laboratory fume hood or a wall exhaust grille.

The laboratory fume hoods are an integral part of the air conditioning system. The only air readily available to operate the fume hoods is the conditioned air exhausted from the module. It was decided that a hood with a 70 inch over-all width was necessary to provide adequate space for the work to be done in it. Experience has shown that the 400 cubic feet/minute of air regarded as ample for the ventilation of a module is only about one-third the amount that is necessary to eliminate fumes satisfactorily from hoods of the size selected. For this reason, a special "self-ventilating" hood was purchased which provides great economy of conditioned air. Auxiliary air at the rate of 800 cubic feet/minute is supplied to a plenum chamber in the back of the hood. This auxiliary air is unfiltered but heated if necessary. It is released into the hood through a ¾ inch wide flat Venturi nozzle which extends across the entire back portion of the hood. The 400 cubic feet/minute from the room combines with this 800 cubic feet/minute of auxiliary air and the entire 1200 cubic feet/minute are then exhausted from the building. The auxiliary air creates a recirculation in the hood as it is discharged through the flat nozzle which, in turn, effectively forms an air curtain so that satisfactory operation is obtained from the hoods with a minimum consumption of conditioned air. The hoods are provided with shutters consisting of a sash containing tempered glass which can only be lowered to a point 3 inches above the bottom of the hood, so that an opening is always available for room air exhaust. All hoods operate during working hours. A special switch is installed in each hood for individual night operation when exhaust fans are normally stopped. Conditioned air supply is at half speed at night, and auxiliary hood supply is off. The laboratory man has no control of his fan in the daytime but he can have his individual hood operate as desired at night. Fume hoods have been initially installed in 49 out of 104 possible locations in the building.

In modules containing no fume hood, the conditioned air is supplied in the usual manner and is exhausted through a grille in the wall. All exhaust ducts serving hoods or possible hood locations are made of acid resistant materials so that they will effectively withstand the corrosive fumes. It will be remembered that these ducts lead to a service floor at the top of the laboratory building. The air from each module is exhausted by an individual blower driven by a motor and a V belt. For a module containing a hood, the fan is adjusted to handle 1200 cubic feet/minute. For a module having no hood, the same size motor and blower are adjusted to exhaust the 400 cubic feet/minute from the room, and the auxiliary air supply duct is sealed. A special set of pulleys is installed to reduce the capacity of the fan where necessary.

It will be of interest to describe some of the machinery that makes it possible to cool the buildings. A mixture of ethylene glycol and water is chilled in a central compressor room and circulated to the air conditioning units, most of which are located on service floors above the buildings. Two "Freon" 11 centrifugal compressors were installed, having respective capacities of 300 and 500 tons of refrigeration. The compressors are located in the Engineering Research Building so that the noise of this heavy machinery is effectively excluded from the main laboratory.

A typical air-conditioning unit consists of four components. The first is the electro-static filter, which cleans the air by ionizing the dirt particles and depositing them on charged metal plates. The second and fourth components are the preheater and reheater consisting of steam heated finned coils, thermostatically controlled. The third component is the chilling unit consisting of finned coils through which chilled water is circulated. A fine spray of water is pumped onto the outside of the chilling coils at all times. This water spray adds moisture to the air if it is required, and it increases the efficiency of the cooling coils under some conditions. Eliminators on the down stream side of the chilling units remove all entrained water particles that might be in the air. There are two characteristic cycles that may take place in the air conditioning unit. In the wintertime the air will be heated sufficiently by the preheater to give a 54° dry bulb reading after the air has passed through the spray unit. Water is added to the air as it passes through the sprays. (Obviously no chilled water is being circulated.) In the summertime, the preheater is idle and the air is chilled to give a 54° dry bulb temperature as the air leaves the spray and chilling unit. Water is often precipitated from the air during this portion of the cycle since it may be cooled below the dew point. In either type of cycle the 54° air which leaves the chilling unit is heated to 65° by the reheater. The 65° air is conducted through the main duct system and heated by a booster heater at the room. It will be noted that the air as it leaves the chilling coil must always be a 54° dry bulb and about 80-100% relative humidity. When this air is heated to 75° F the relative humidity is thereby reduced to approximately 38 to 48%, which is a suitable humidity for uniform testing conditions and is also comfortable for the workers. It will be seen that the air is dried in the summertime by chilling below the dew point, and moisture is added in the wintertime as the air passes through the water sprays.

Special provisions were necessary in some laboratories to accommodate the work intended for them. Independent air-conditioning systems were installed to obtain extremely close control of both temperature and humidity for textile research and for some of the physical testing of rubber and plastics. Another room has special spray nozzles to maintain the relative humidity in excess of 50%. This high humidity is necessary to eliminate static electric charges on samples that are being weighed on precision analytical balances. The relative humidity in the infrared spectrometer room is never allowed to rise above 30%. Infrared spectrometers utilize sodium chloride crystals for lenses, prisms and windows, and any condensation of moisture on the crystals would instantly destroy their optical surfaces. Air conditioning for the assembly hall and the cafeteria is independent of the main systems because of the exceptional heat loads in these areas.

LABORATORY FURNITURE

The principle of flexibility or interchangeability, characteristic of the modular system in general, was also applied to the design and selection of laboratory furniture. A revised design of metal laboratory work table was chosen, with rounded corners to present a pleasing appearance. Each table unit is equipped with one of seven interchangeable arrangements of drawers, cupboards or combinations of both, all having the same outside dimensions. A compound of black natural rubber is used for the working surface of the tables and the edges are bound with a polished stainless steel molding. A cross section through the tabletop reveals: ⅛ inch of rubber calendered and cured onto a cotton duck backing, 1/16 inch aluminum, ¾ inch waterproof glued plywood and 1/64 inch aluminum. All of these components are securely cemented together under heat and pressure. The plywood contributes strength and rigidity to the assembly. The 1/16 inch aluminum under the rubber face material distributes concentrations of heat and prevents damage to the top materials. The 1/64 inch aluminum at the bottom is to prevent warpage of the plywood from moisture or other causes. Rubber is an excellent material for a working surface. Its resilience minimizes glass breakage. At the same time it presents a "warm feeling" surface on which to work. Natural rubber is resistant to most of the common acids and alkalies. It is realized that prolonged exposure of the tops to certain solvents or oils would cause the rubber to swell, so that some simple precautions have to be observed. The rubber will take ordinary waxes and can be cleaned to give a very attractive appearance. A 10 inch wide by 44 inch high laboratory service island was designed to carry all services. All of the valves or cocks extend through a metal face above the table working surface. One and one-fourth inch black carbonized birch is used to furnish a chemically resistant top for reagent bottles. This is one of the few instances of the use of wood in the buildings.

Several other categories of laboratory furniture, notably distillation racks, laboratory tables and storage cabinets, were designed so that the items within each category would have the same over-all length, thereby permitting the interchange of items of variable design. Storage cases are all seven feet high, with the front consisting of two sliding glass doors. An 18 inch wide clothes locker is provided in each laboratory unit. The lockers are also 7 feet high and are usually placed adjacent to storage cases. Stone laboratory sinks are usually installed back to back in the middle of the service island unit. Each sink has a hot and cold water mixing valve as well as two additional cold water valves for vacuum ejectors or other purposes. If distilled water is desired, a silver-lined, self-closing cock is substituted for one of the individual cold water valves in the sink. If a machine that requires some of the standard services is installed in the laboratory, it is located next to an island. In such case the laboratory table or rack is omitted and the 10-inch wide island serves as a means of concealing the services. It should be noted that a strict policy is established that all pipe and conduit must be concealed. This policy is effectively executed without jeopardizing maintenance of the system by bringing the services through the service island from pipe bands back of removable metal panels.

Wherever possible, laboratories were equipped with these standard furniture selections. The actual arrangement is made to suit the work to be performed. A few exceptions were made for special applications such as a titration table, wiring benches, photographic dark rooms, etc.

Single pedestal desks are provided for technical men and are located in their respective modules. They are painted green to match the laboratory furniture and blend with the existing color scheme. Grey metal furniture was selected for all areas devoted strictly to office work. The neutral grey color distinguishes the offices from the laboratory areas and still harmonizes with the colors selected for walls and floors.

SPECIAL PROVISIONS FOR SERVICE FUNCTIONS

Many special provisions have been made to assist the "Operating and Planning" or business department in providing their services to the Research Center. It is intended that the research scientist be relieved of all possible routine work so that he can concentrate on his research work. Space does not permit a detailed discussion of each of these items, but a brief mention of some of them may be of interest. A suitable lobby is provided to receive visitors and register guests. The telephone switchboard is located in the lobby so that the receptionist serves as a combined receptionist and telephone operator. The telephone operator answers only "outside" calls to and from the Research Center, since all internal calls are handled automatically by the dial system.

An assembly hall is provided which comfortably accommodates 300 people. It is designed primarily for technical meetings. For this reason, it is equipped with a raised platform or stage with a built-in screen for projecting still or moving pictures. There are two conference rooms, which are actually a one- and two-module room, respectively, but without the laboratory furniture to be found in the standard modules. The conference rooms are separated from each other and from the assembly hall by accordion type folding doors. These doors can be opened so there is one large conference room, or the rooms can be used to serve as an overflow for the auditorium. The general arrangement of these rooms can be seen in figure IV.89.

A cafeteria and kitchen have been provided to serve 225 people. The dining area has been made very attractive and will accommodate half of the Center employees at one time. Experience has shown that the rotating system has worked very successfully and gives adequate service to the research personnel.

A registered nurse is on duty at all times, and a single module room has been devoted to first-aid treatment. It is equipped with observation chairs, sterilizers, lamps and other essentials for the treatment of injuries.

A vault to house the central research files is situated on the first floor of the main research laboratory building. This vault is actually a fireproof room within a fireproof building. A heavy steel door with a combination lock has been provided. For fire protection, a carbon dioxide system has been installed in place of water, which might damage the records.

Standard metal shelves have been installed in a six-module room which serves as the chemical store room for the entire Center. Special consideration is given to the storage of unusual items such as glass tubing, and a fume hood is provided for handling or weighing volatile chemicals.

A single-module room has been set aside for the cleaning of laboratory glassware. An electrically heated acid bath is used for this cleaning. The room has tile walls, and special acid-proof tile was used for the floor. This is one of the few cases where an unbalanced condition is maintained in the air conditioning system. The room is kept under a slightly negative pressure to prevent the escape of acid fumes. If these fumes should escape to other parts of the building, they might cause a great deal of damage. All of the fumes are effectively removed through a special hood directly over the heated acid bath.

At three locations in the Center special rooms have been designed for processing photographic materials. This is another advantage of the windowless design, as dark rooms can easily be established if properly planned.

Two locations are provided with pairs of cold rooms. The first room of each pair is maintained at 32° F. The second room is entered through the first room and is maintained at -14° F. Many of the chemicals which have to be stored for long periods of time must be held at low temperatures or high pressures. These rooms effectively cool the chemicals, and leakage through bottle seals is minimized.

OFFICES

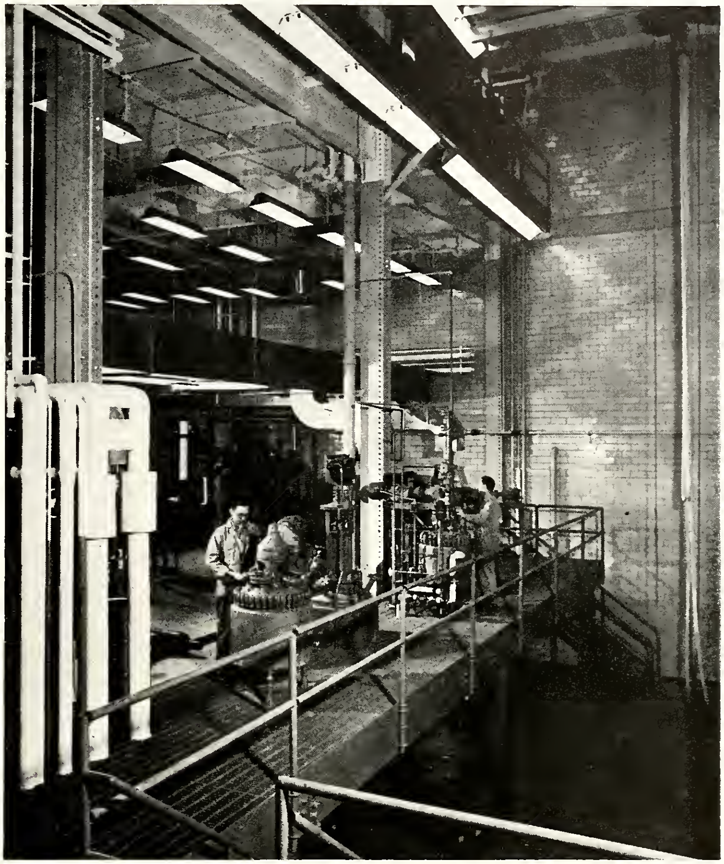
Offices for directors of departments are grouped in pairs wherever possible, with a third office for a secretary shared by two directors. These offices are located adjacent to the other activities of the departments concerned. A typical example of the arrangement is shown by room 229 in figure IV.89. It can be seen that the three offices occupy two modules. The room which is entered first from the corridor is the secretary's office and contains the files for two departments. The two inner rooms are private offices for the directors. Other provisions for office functions at the Center include a three-module room for a general office and a two-module room for engineering design and supervision. In keeping with the scheme of flexibility, all office rooms are either single modules or multiples of the standard module, with movable furniture and other standard office equipment. Any of the offices can be converted to laboratory space without excessive expense and with no major changes in the building construction, since capped tees for all services are provided in the pipe bands back of the wall furring.

LIBRARY

Adequate library facilities are extremely important to a research organization. Suitable facilities are provided for the 10,000 volume library, a photograph of which is shown in figure IV.92. Racks are provided for both books and periodicals. The current issue of each periodical is placed on a sloping shelf, with back issues directly beneath on a horizontal shelf. In this way, desired periodicals can easily be identified by the covers. Small rooms are adjacent to the library for patent files, microfilm reading and book repairs.

ENGINEERING RESEARCH BUILDING

The engineering research building is more of a fixed-purpose structure than the main research laboratory. The types of functions that are housed in this building require more permanent walls than the basic type



IV.93 A general view of a high area in the Engineering Research Building.

of laboratory work performed in the main research laboratory building. The two buildings, approximately equal in size, are only 25 feet apart and are apparently connected by a covered passage. Actually, the two structures are only connected by pipe and copper flashing, since there is a 2-inch void between the buildings to prevent the direct transmission of vibration. Types of work conducted in the engineering research building include chemical engineering research, physical testing and the heavier physical research; it also contains the engineering shops, boiler room and air conditioning machinery.

The chemical engineering research department conducts pre-pilot plant types of work. The areas devoted to this work are designed to expand the "test-tube and beaker" work performed by the chemists in the main laboratory to the larger corrosion resistant metal or glass-lined metal apparatus. These areas are supplied with the same services as in the main laboratory. In some cases, additional services such as 150 psi steam, vacuum, refrigerated chemical storage tanks and tower water for cooling have been furnished. Some of the areas are one story high while others are two and even four stories high to accommodate the erection of large equipment or tall distillation columns. Fins have been welded to the building columns to provide a means of fastening equipment without defacing the fundamental building structure. A general view of one of the high areas is shown in figure IV.93. Another area, three stories high, has a complete installation of explosion-proof electrical equipment for work involving flammable materials. This explosion-proof area is also provided with windows which serve as a pressure release. The steel sash is held in place by clips which are relatively weak. The window glass and frames would be blown out of their casings if a blast should occur, thus preventing damage to the roof or other areas within the buildings. There are vestibules at all entrances which function as air locks.

Research on rubber and rubber-like materials requires a fairly large amount of standard compounding, curing and testing. Many of these tests are conducted to ASTM specifications. For this reason, a separate department has been established whose primary responsibility is to conduct the bulk of the standard types of tests for all technical men at the B. F. Goodrich Research Center. This department is well equipped with compounding rooms, mills, curing presses and other machinery necessary for the preparation of samples. A special testing room with close control of both temperature and humidity was installed for final testing. Equipment of this type has presented new problems in the design of the air conditioning system. Many of the machines are hooded to prevent an objectionable dust condition. The rooms have conditioned air supplied and exhausted. Where special hoods over machinery have been installed, a special exhaust fan is provided to remove the fumes. The operation of this special exhaust fan is controlled by the operator in the laboratory. Electrically connected to the switch operating the exhaust fan is another auxiliary air system which supplies sufficient make-up air to the room to balance the increased quantity exhausted through the hood over the machine. In the case of the mill room there are five of these special hoods in addition to the standard air conditioning system. Each of the hoods is individually controlled as desired by the operators, and an amount of auxiliary air is supplied in proportion to the number of hoods in operation.

Curing presses are always a source of objectionable heat. The presses have all been installed in a 10'0" by 30'0" room, which is separated from the operator's room by means of a metal partition. The front of each curing press is built into the partition, and molds are loaded into the presses through a small vertical lift door. All of the press controls and temperature recorders are flush mounted on the operator's side of the partition. The heat is thus effectively sealed in a room away from the operator.

The physical research department is in the peculiar position of operating both vibrating machinery and very delicate laboratory equipment. Examples of the former are flexing machines that inherently transmit vibration to the building; examples of the latter are the electron microscope and other delicate optical equipment which must be mounted free from all disturbing vibrations. For this reason, the department has been divided into two portions, with areas in both the main research laboratory and the engineering research building. The portion in the engineering research building is devoted to the heavier types of testing machines, low temperature refrigerators and research projects which require test development. Actually, the department occupies a small area on all three floors of the engineering research building. A section of the floor space in each case is made of removable steel plate which makes it possible for the physical research department to conduct experiments which would require head room greater than available on the one floor level.

Engineering shops have been set up in the engineering research building which will accommodate all of the common trades. Tooling is necessarily limited to relatively small work, but its scope has been made as broad as possible to cover many requirements. These shops must satisfy two classes of demands for their work. One is the construction of new equipment for the laboratory research projects; the other is the maintenance of the buildings and building services. One room is devoted entirely to lathes, drill presses, milling machines, grinders, etc. Another larger room contains the balance of the tools and accommodates sheet metal work, a welding enclosure, pipe cutting, carpentry and an electrician's bench. This large room uses space economically because the working areas of one machine often overlap another. No attempt is made to use all the machines simultaneously but they are available when required. One small area in the machine shop is isolated from the rest and contains a lathe, drill press and a set of hand tools. This area is for the use of any technical man who may have a small job to do. Since it is adjacent to the machine shop, professional advice and assistance is always at hand. The technical personnel normally have their work done in the regular shop.

A large area on the ground floor of the engineering research building is devoted to "Freon" compressors for air conditioning and a boiler room for steam generation.

HI-VENT BUILDING

A building with an area 21'0" by 30'0" was constructed for work involving explosive or toxic gases. A special ventilating system with a maximum capacity of 20,000 cubic feet/minute is capable of changing the air every half minute. The outside air is heated as it passes through steam unit heaters and is then introduced through the ceiling of the room through perforated tile. The air then passes over the operators, past the laboratory equipment and then through slots in the floor to a plenum chamber which extends under the entire floor area. It is about 3 feet deep and collects all of the ventilating air, which is then exhausted outside through a short stack. The original installation provided alternate pieces of solid checkered plate and open grating over the slots. In place of this pattern, the open grating may be concentrated near apparatus requiring special ventilation, leaving the solid plate in idle parts of the room. It can be seen that the building functions as a large down-draft hood.

HI-PRESSURE BUILDING

A separate building with floor space approximately 18'0" by 40'0" is provided for high pressure reactions. Within the building are three 3-sided cubicles formed by 12 inch thick reinforced concrete walls. The south wall of the building functions as a fourth side of the cubicles. This wall contains steel sash and glass windows, the frame of which is held in place by small clips which would release the entire sash in case of a blast. Operations are observed from an area outside of the cubicles. Pipe bands are mounted across the back of the enclosed areas with tees supplying services through the concrete walls. Narrow peep slots looking upward at a 45° angle are provided for observing equipment. It is necessary to mount a mirror inside the cubicle for visual observations. Other holes for operating rods or control equipment are provided through the concrete walls. These holes for operating rods are never in line with the peep slots so that the operator is always protected while making any observations.

SOLVENT STORAGE BUILDING

A separate building has been provided for the bulk storage of solvents in drum quantities. The building will accommodate approximately 100 drums of solvents as well as a separate Government-approved storage case for tax-free alcohol. This building is also windowless and has been set apart from the other buildings because of the hazards involved in storing highly flammable materials.

UTILITIES

Five public utility services are supplied to the Research Center: electricity, gas, water, telephone and sewer. Some of the most important services provided to the buildings, such as steam, are generated at the Center.

Electricity at 4600 volts is conducted underground in lead cables to the inside sub-station. Only two of the large motors operate with 4600-volt power. The balance of the power is reduced to 440-volt Y-connected circuits. It is of interest to note that the fluorescent lights are installed with 265 volts supplied to the ballasts and are connected directly across one leg of the 440-volt system. This makes it possible to feed the lighting system from the 440-volt Y-connected circuits without the use of transformers. DC is supplied by converters in each laboratory where desired. There is also an adequate supply of 110-220 single-phase three-wire power for low-voltage requirements of apparatus in the laboratories and miscellaneous engineering operations.

Natural gas, used for fuel in the boilers, is piped throughout the building for laboratory service.

Water is supplied from the city mains direct to the domestic water system or to a 300,000-gallon underground reservoir. This reservoir serves both as a supply for laboratory water and as a reserve in case of fire. The pressure in the laboratory water system, created entirely by pumps, is kept under close control by using a ballast tank. The ballast tank has two types of control. One is a liquid-level control and the other is an air-pressure control. The liquid-level control operates the pumps as required. The pressure control maintains a relatively constant pressure at all times. The use of this ballast tank and its controls completely eliminates the need for an outside standpipe and precludes continuous operation of the water pump. Domestic and laboratory hot water is steam heated and supplied throughout the buildings in a circulating system.

A steam-heated water still is operated in each of the two large buildings. The water, stored in aluminum tanks, is distributed throughout the buildings in aluminum pipes.

Refrigerated water is supplied to limited areas in the Engineering Research Building. This is 40° F water, which is used on laboratory mills and other equipment which cannot be cooled adequately by other means.

An auxiliary recirculating system of cooling water is also provided for certain of the building services and laboratory requirements. This water is cooled in the same tower that is used for the large air-conditioning compressors. This system is used where the cooling requirements are too large to use process water, which would be wasted to the drains.

Dry saturated steam is generated at 150 psi in either of two 15,000-pound/hour water tube boilers. The boilers are normally gas-fired but are equipped to use fuel oil in emergencies. They have the normal auxiliaries including steam-driven forced-draft fans, induced-draft fans, feed water heater, feed water pumps, etc. Some of the steam is used at full line pressure. Reducing valves furnish 50-psi steam for many laboratory requirements and the balance of the steam is used at 5 psi for heating purposes.

The buildings are equipped with a complete dial telephone system for quick communication. There are direct tie lines to the Akron plant and adjacent cities.

Sanitary and industrial sewerage is installed as separate systems in the buildings. The industrial sewerage has a 1500-gallon delay reservoir or sump for neutralization, and the sewage must spill over a lead V-notched weir for aeration. The two sewerage systems then join and are connected to the county sewerage system. Electrodes in the industrial sewage sump are joined to a pH recorder controller. A continuous record is made of the pH of this waste, and gaseous ammonia is bubbled through the sump for neutralization when the pH falls below a specified minimum. Cast-iron pipe has been used for industrial drain lines wherever possible.

SELF-SUFFICIENT PROTECTION

It will be noted from the previous description that adequate protection of the buildings can be maintained even though one or all of the utilities supplied to the

Research Center may be discontinued for a long period of time. The underground water reservoir is piped in such a manner that only half of it could possibly be used in the process water system during periods of high demand. Therefore 150,000 to 300,000 gallons of water will always be readily available for the fire pumps in cases of emergency. The boilers can be operated without electricity and therefore can always supply steam to the turbine-driven fire pump. Approximately 10,000 gallons of fuel oil are kept on the property at all times as a standby and can be used as an alternate fuel in the boilers in case of a failure in the natural gas supply. A small turbine-driven generator located in the boiler room has sufficient capacity to supply the entire emergency lighting system. While the laboratory could not operate under certain emergency conditions, essential safety systems, such as the emergency lights and the fire alarm system, would still be active, and water pressure could be maintained in the fire mains at all times.

CONCLUSION

Two years of operation at the Research Center have proved that the basic design agreed upon was well suited for the type of research exploited by a rubber and chemical company. The establishment of a separate staff to conduct research, away from production, has been very advantageous. Many difficult situations have been quickly solved by cutting routine methods without departing from sound business practices. The personnel are quite happy to work in a windowless building free of noise, dirt and vibration. This attitude should foster the accumulation of fundamental knowledge that will ultimately result in better products.

12

BUREAU OF MINES PILOT PLANT LABORATORY

H. P. Greenwald and Earle P. Shoub

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These laboratories, designed by the architectural firm of Prack and Prack, were constructed during World War II as part of a program originated for study of means of producing liquid fuels from solid or gaseous materials. Their primary purpose is to provide facilities for studying the direct hydrogenation of coal (Bergius process) and synthesis of liquid fuels from mixtures of carbon monoxide and hydrogen (Fischer-Tropsch process). The scale of work ranges from laboratory to pilot plant, a fact that influenced a number of design features.

FACTORS INFLUENCING DESIGN

As construction of this plant was a war measure, speed was a prime necessity. There was not time to develop in complete detail the various design features of the pilot plants before beginning construction. It was necessary to fix upon certain general principles, decide upon minimum and maximum dimensions, estimate maximum service requirements, consider those safety requirements that would influence design, and integrate these into a design which could be translated into immediate construction under the restrictions on manpower and materials then existing. Thinking along these lines was primarily utilitarian; but within the dimensional and financial limits set, the architect was free to produce as pleasing an exterior design as possible.

The legislation authorizing this project specified a term of five years for the construction and research. To erect structures that would meet the requirements of the case on the one hand, and have such a short life on the other, was a practical impossibility. Therefore, a permanent type of construction was adopted having the greatest possible flexibility of use under the theory that safety demanded such action.

GENERAL LAYOUT

The final result was the group of buildings shown in figure IV.94. Selection of the site was determined largely by the facts that the Bureau of Mines controlled ample land at this point (one mile south of Bruceton, Allegheny County, Pa.), and that natural gas, high-voltage power, water supply, and access by rail and highway were already present on the property. The building on the lower level beside the railroad houses a steam-generating plant and equipment for the preparation of coal required for the studies of direct hydrogenation and gasification.

Original plans called for a group of four principal buildings on the main operating (upper) level, of which only three were constructed. These buildings have their major axes in a north-south direction. The one in the foreground of figure IV.94 was designed for studies of direct hydrogenation of coal, and the one in the rear for studies of the gas-synthesis process. The smaller central building houses administrative offices and services for the other two and is connected to them by bridges at the second-floor level. The fourth building was to have been constructed in the open space to the left (south) of these three, with its major axis in an east-west direction, and was intended to house all offices and service laboratories, leaving the present group free for development work. However, inflated costs made it inadvisable to construct this fourth building at the time, and the work planned for it was crowded into the other buildings.

Research of this type requires large volumes of carbon monoxide and hydrogen, and an outdoor plant for production and storage is seen in the yard at the right (north) of the three principal buildings. There are, in addition, several small buildings for storing flam-

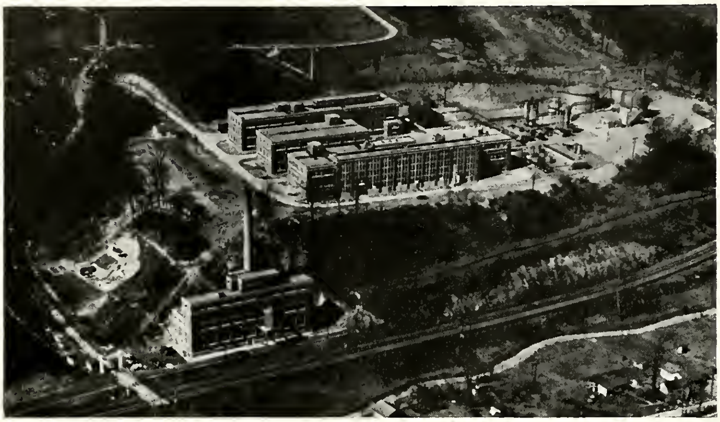

Figure IV.94 Aerial view of Research and Development Laboratories, Office of Synthetic Liquid Fuels (Bureau of Mines, United States Department of the Interior).

mables and housing specific operations considered too hazardous for inclusion in the main buildings.

STRUCTURAL FEATURES OF BUILDINGS

Before its selection, the area covered by the plant was bare of improvement and had to be graded to the levels shown. Because of fire hazards attendant on this type of experimentation, it was decided that only incombustible construction would be used.

The boiler house is of a standard design with overhead coal bunkers. Placing within it the apparatus for preparing coal necessitated some minor modifications in equipment, so that coal shipments could be handled either to the boilers or the preparation plant. In addition, coal rejected in the latter is passed to the former. The space for the preparation equipment is merely one large room occupying the left (south) three-eighths of the building as seen in figure IV.94. Steam and return lines to other buildings are of specially insulated pipe buried directly in the ground. Construction of tunnels was considered unjustifiably expensive.

The design of the central service building is quite conventional, except for the area devoted to the plant's principal instrument and machine shop. One half of this area is of double height and is provided with a traveling crane for handling heavy equipment.

Special designs were required for the coal-hydrogenation and gas-synthesis buildings. The coal-hydrogenation building required a high bay to house high-pressure converters and distillation columns. This work was considered to carry enough fire and explosion hazard to require isolation from it of operating personnel to the greatest possible extent. This was achieved by the scheme shown in figure IV.95, which is a typical cross section looking north. The operating bay is at the right and is separated from the balance of the building by a heavy concrete and steel wall designed to resist explosion pressure; it is highly improbable that any part of this wall could be punctured, and it is designed so that the total thrust of an explosion would be absorbed into the main frame of the building back of it. The opposite wall is glass in a steel sash, with a few panels of corrugated transite near the ground, and is designed to act as a pressure-relief area. This area of glass is facing the observer in figure IV.95, which shows also that the portion of the building having three floors surrounds the high bay on three sides. All controls for operations in the high bay are located in an operating corridor on the opposite side of the explosion-resisting wall (see figure IV.95). Other equipment, such as pumps, compressors and mixing devices for powdered coal and oil, are located in the areas to the left on the first and second levels.

The south end of the high bay is designed as a fitting room. To facilitate assembly and disassembly of tall converters, there is a pit in the floor 10 feet square by 20 feet deep into which a converter can be lowered. This gives a total clearance under the crane hook of approximately 60 feet.

A different arrangement was used in the gas-synthesis building. The explosion hazard there was considered to be subordinate to the health hazard arising from carbon monoxide, and explosion-resisting construction was not used. Also a larger area for pilot plant work was desirable, but head-room over a considerable portion of it could be less. Essentially the building is divided into two parts, with the pilot plant area to the north and ordinary 3-floor construction to the south of a

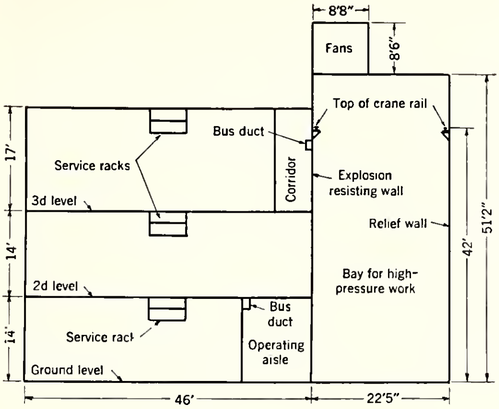

Figure IV.95 Typical cross section, coal-hydrogenation building. Horizontal dimensions on center lines. Vertical dimensions on floor levels. Length of building 300 feet, length of operating bay 200 feet (Bureau of Mines, United States Department of the Interior).

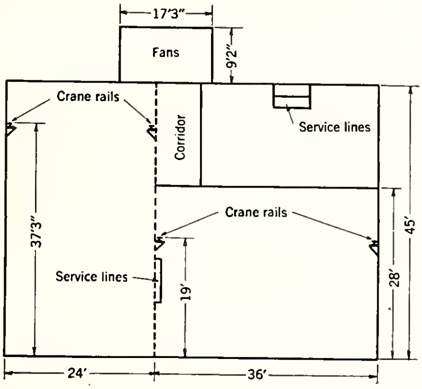

Figure IV.96 Typical cross section of gas-synthesis building. Horizontal dimensions on center lines. Vertical dimensions on floor levels. Length of building 240 feet, length of pilot-plant area 140 feet (Bureau of Mines, United States Department of the Interior).

dividing wall. Figure IV.96 is a typical cross section looking south in the pilot-plant area. There are two main working areas, one higher and narrower than the other. Over the lower area are an operating corridor and laboratory space on the third-floor level.

All the above buildings are steel-framed, with concrete floors. Steel doors and window frames were used. Exterior walls are red face brick on the exterior and mainly glazed tile on the interior. Terra cotta was used for window sills and for trim. Interior partitions are mainly glazed tile. The coal-hydrogenation and gas-synthesis buildings have stairways at both ends and at the middle, but one of these in each building is an escape stairway only. Each of these two and the service building are provided with a freight elevator with a platform 7'0" by 10'0" and a capacity of 4 tons. In general, these buildings have no basements, except for small areas required for sump pumps and entrance of services. An exception is a partial basement in the service building designed for heavy storage.

SERVICES AND SHOPS

The nature of the work done in this plant required a number of services, some of which are not common in research operations of other types. Services may be divided into two categories, according to their nature, which may be termed common and special. Common services are heat, light, power, hot and cold water, and sewers. Special services include compressed air at different pressures, natural gas, hydrogen, synthesis gas (different mixtures of carbon monoxide and hydrogen), inert gas, distilled water, circulating cooling water, process steam, ventilation, and cranes in pilot-plant areas. Under crafts there must be supplied the services of machinists for rough and high-precision work, welders, carpenters, electricians, and pipe fitters. One may argue whether a given service (compressed air for example) should be classed as common or special. The division here is based on whether or not intended use of the service required special attention during design rather than on the frequency with which it is met in other research installations.

Accessibility was a fundamental consideration in this particular design. To meet this, no service line of any kind is buried in a wall within the buildings. Similarly, no service line is buried in a floor above ground. The service lines are grouped on racks, some of which are indicated in figures IV.95 and IV.96, the cross sections of the two principal buildings. The pipe lines along these racks have tees closed with nipples and caps at 10-foot intervals for ready access; in many places, valves are in place ahead of the cap so that a connection can be made without shutting off the main. Electrical service other than lighting is mainly through bus ducts, with taps and switches at intervals as needed.

Distribution of the special gases from the generating plant presented only a piping problem common to many industries, but their use is at elevated pressures, and the location of compressors was a problem given much thought. The extreme case is hydrogen for the direct-hydrogenation process, which may be used at pressures ranging up to 1000 atmospheres. For these high pressures the compressors are located as close to the point of use as possible. On the other hand, synthesis gas is used at about 40 atmospheres, and the compressors are located in a separate smaller house at the north end of the gas-synthesis building, the gas being piped to points of use at full pressure. Similarly compressed air is furnished to many points from a single compressor.

Distilled water is employed in large quantities at a number of points, and a single, steam-powered distilla-

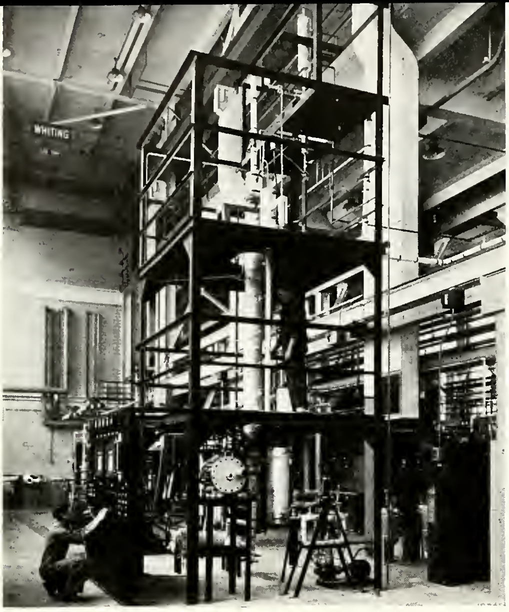

Figure IV.97 View in high crane bay of gas-synthesis plant (Bureau of Mines, United States Department of the Interior).

tion plant is used with storage tanks in the penthouses of the two principal buildings to which the distilled water is pumped. Aluminum pipe was the best material obtainable for the distilled-water lines, and was used.

A large volume of cooling water is needed, and as the entire property depends on a 4-inch water line, conservation is mandatory, regardless of financial considerations. A circulating system for cooling water was installed which incorporates a cooling tower, which can be seen immediately in front of the gas holders and to the right of the gas production plant in figure IV.94.

Waste gas is disposed of by a piping system leading to a flare stack, which stands on the hillside behind and above the gas-synthesis building as seen in figure IV.94. At some points, connections to this system permit dumping the gas and vapor contents of experimental equipment in case of emergency. Such a system must of necessity be designed for maximum expected load and normally operates at a very low load factor.

Ventilation was a problem that received special attention because of the potential hazard from flammable and poisonous gases or vapors which might escape through slow leaks or be suddenly released in quantity by the failure of equipment or of a pipe line. Particular attention was paid to the pilot-plant areas. In the direct-hydrogenation process, the principal hazard is hydrogen, which rises to the ceiling immediately if released. Consequently, ample exhaust ventilation is provided along the ceiling, with fresh air entering through heating coils near the floor. In the gas-synthesis work, the principal hazard is carbon monoxide because of its high toxicity in small concentrations. Here it was not considered proper to allow movement of the room atmosphere for considerable distances before it entered the exhaust ducts. The pilot-plant area for gas synthesis contains two large fans which draw fresh air through heating coils and discharge into two ducts running the entire length of the area beneath the floor. From these riser ducts placed at short intervals distribute the air to the room. A second set of fans in the penthouse exhausts air through ducts running down from the ceiling in which openings can be provided at different elevations as needed.

Figure IV.97 is a view in the higher bay of the pilot-plant area of the gas-synthesis building. The exhaust-air ducts running up to the ceiling are along the dividing plane between this and the lower bay; the fresh-air ducts are along the opposite wall and out of the picture to the left. The runs of service piping are behind the exhaust-air ducts, and a bus duct for electrical service is in front of them. The structure supporting the experimental equipment shown in this picture is free standing and not a part of the building; it can be altered or removed altogether at any time.

Figure IV.98 shows the arrangement of services in a bench-scale area. The term "bench-scale" is used to designate equipment that can be placed in a room of

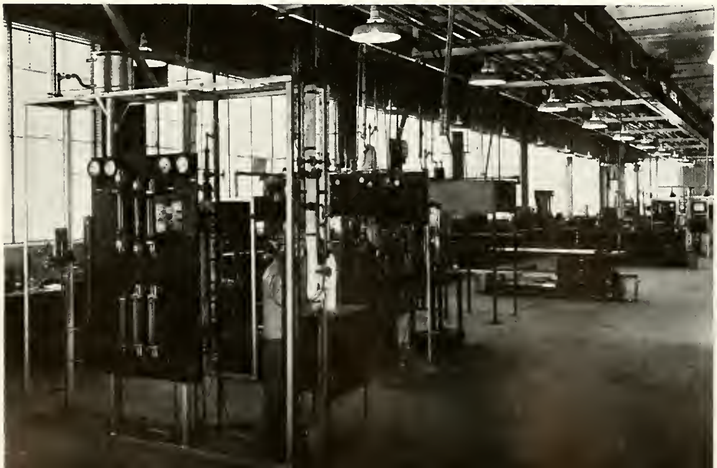

Figure IV.98 View in a bench-scale area of the plant (Bureau of Mines, United States Department of the Interior).

ordinary height and is the immediate precursor of pilot plant-scale equipment. Here the service lines are carried on an overhead rack. The same arrangement of services is used in chemical laboratories, as shown in figure IV.99.

Shop services are a prime necessity for work of this kind. Precision machine work is concentrated in a shop in the service building, which is called upon to fabricate items from many metals and with weights ranging from a few grams to hundreds of pounds. Machines for handling the heavier work are concentrated in the higher portion of the room, which has crane service.

Each of the two principal buildings has a shop for rough work in assembling and repairing the pilot plant equipment. These are immediately adjacent to the pilot plant areas. Thus there are different crews, depending on the nature and precision of the work. It has been found advisable to extend this system of operation to electrical and pipe-fitting work as well. Thus the crews that maintain the common services do not maintain those that are highly specialized. For example, the installation and servicing of high-pressure hydrogen lines requires use of a highly specialized technique.

SAFETY CONSIDERATIONS

There are considered here only those safety features that are either unique or required because of the special conditions in the work to be performed in these buildings. The hazards inherent in the work for which constructional provision had to be made are fire and explosion and the toxic and comfort effects of poisonous and noxious gases. The coal-hydrogenation work employs hydrogen at pressures up to 15,000 psi, and the gas-synthesis work employs synthesis gas, which is a mixture of carbon monoxide and hydrogen at pressures up to 600 psi. The principal hazard of this mixture is carbon monoxide poisoning. The products in both instances are hydrocarbons ranging from the very-low-boiling, highly flammable ones all the way to higher boiling-point waxes, which are less dangerous materials. Some of the products in both plants have very strong and objectionable odors and are harmful enough from a health standard to make it advisable to keep their concentration at a low level.

Ventilation was a prime consideration. In such a case, one must consider possibilities and probabilities. Maximum safety in such matters is achieved only by putting the plant out of doors, an impossibility in the climate of western Pennsylvania. A reasonable compromise must be made and the ventilation designed on that basis. Factors to be considered are allowable concentrations of the various vapors and gases and their physical properties, particularly specific gravity. In order to handle a leak of any magnitude in the gas-synthesis building, or to clear the building after a major leak, two auxiliary roof ventilators were installed, each of which will give four air changes per hour. Normal ventilation is six changes per hour, and the maximum is consequently 14 changes per hour.

Much thought was given to the electrical system, and it was decided that each building should be provided with its own circuit breakers, placed either in an innocuous location or immediately outside the building. In the case of the coal-hydrogenation building, where the major hazards are from hydrogen and hydrocarbon products, the wiring and installations are, wherever possible, in accordance with Chapter V, Article 500, of the National Electric Code. At the time of construction, the equipment available was Class I, Group D, and virtually all of the wiring is in accordance with that standard. On the ground floor in the center of the building is a corridor into which fresh air is blown to maintain a slight positive pressure at all times. The electrical controls for the building and the instrumentation for the high-pressure pilot plant are installed in this corridor, which is separated from the high-pressure pilot plant by the explosion-resisting wall previously described. In considering the gas-synthesis building, it was felt that the hazards from carbon monoxide poisoning were much greater than those from an explosion due to a gas leak. In general, it was assumed that the carbon monoxide alarms which sound a warning at a carbon monoxide concentration of about 0.02% would warn the operators and other personnel of a gas leak

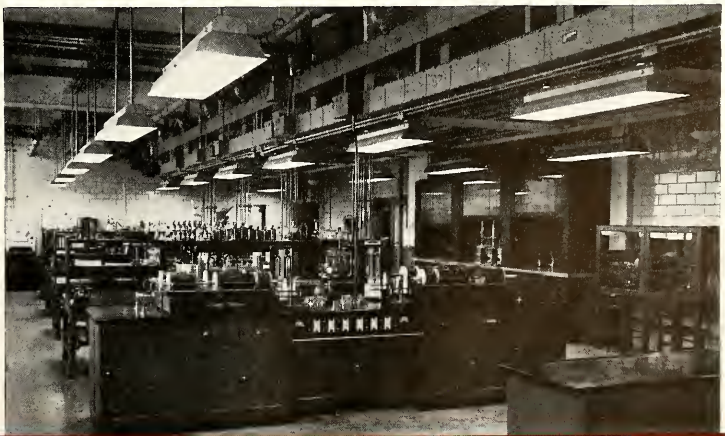

Figure IV.99 View in a chemical laboratory (Bureau of Mines, United States Department of the Interior).

long before it reached an explosive mixture. In this building, it was therefore decided to employ explosion-proof lighting in the pilot-plant area but to utilize no other electrical safeguard of that type.

All buildings are served by an emergency lighting system, which consists of generators driven by internal-combustion engines operating on natural gas. This system is automatic and goes into operation immediately upon the interruption of the lighting circuit to any building. Strategically placed lights were chosen to be connected to this system through a 3-way switching arrangement, so that illumination for corridors, escape doorways, stairwells, etc., would be provided if power failed, even if the failure were caused by an accident of some sort originating within the plant itself. A similar system is being installed to provide continued operation of the electric motors and controls in the boiler plant, condensate return pumps, other sump pumps, emergency ventilation, and any other services whose continued operation is essential.

In addition to the foregoing provisions, it was decided that all electrical equipment would be grounded, that spark-proof blades be employed on all ventilating fans and that static-free belts and static-electricity collectors be employed for all fans and compressors. Lightning protection was provided for all buildings, gasholders, stacks, yard piping, and other sufficiently tall structures.

Other hazards not covered in the foregoing are gas-fired equipment, compressors for synthesis gas, storage of hydrocarbons and storage of cylinders containing flammable or toxic gases. Two one-story sheet-metal buildings were erected, one for the gas-fired equipment, and the other for the compressors, in addition to which a small installation of extreme hazard was placed in the open. A one-story building of brick construction similar in physical appearance to the major buildings was provided for the storage of flammable liquids. This appears to the right of the coal-hydrogenation building in figure IV.94. In this building were provided racks for holding 55-gallon drums, shelves for small containers, and an automatic carbon dioxide flooding system for smothering fires. At the outskirts of the plant area is a shed for storing gas cylinders, arranged in stalls so that each of the various gases will have its own storage area; the empty or partly empty cylinders are kept separate from those that are fully charged.

The gas-cracking plant for the production of hydrogen and synthesis gas from natural gas, and the gasholders for the storage of these gases are also somewhat removed from the major buildings as figure IV.94 shows.

Fire-fighting provisions include an electrical fire-alarm system, standard hydrants, hose cabinets in stairwells and halls of various buildings, and a standpipe which is in turn connected to pumps in the boiler house; these pumps can provide the full capacity of the city water system, feeding the property. Because flexibility of operations is necessary, it was decided to keep the permanently installed fire-fighting equipment to a minimum and to use many portable extinguishers, the locations of which are changed as modifications in the equipment make it advisable.

OCCUPANCY

The following table shows areas and volumes of the total plant devoted to different purposes. This summary excludes the boiler house, the gas production plant and the gas holders. Drafting is included with mechanical services.

UTILIZATION OF SPACE

Use	Floor area		Volume	
	Sq. ft.	Percent of grand total	Cu. ft.	Percent of grand total
1. Experimental				
a. Pilot-plant scale	26,361	22.2	719,974	35.5
b. Bench scale	4,684	3.9	71,000	3.5
c. Laboratory scale	18,404	15.5	264,234	13.0
d. Subtotal	49,449	41.6	1055,208	52.0
2. Supporting services				
a. Mechanical	27,503	23.1	405,336	19.9
b. Stores	13,824	11.6	164,898	8.1
c. Office	10,409	8.8	153,727	7.6
d. Employee conveniences	6,765	5.7	97,937	4.8
e. Corridors, stairwells	10,934	9.2	155,132	7.6
f. Subtotal	69,435	58.4	977,030	48.0
3. Grand total	118,884	100.0	2032,238	100.0

13

UNIVERSITY OF ILLINOIS, PILOT PLANT LABORATORY

H. F. Johnstone

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In the universities, as well as in industry, it is often necessary to provide facilities for development work in which large scale equipment can be constructed and operated continuously for periods of several months. The problems involved in erecting heavy equipment, in supplying sufficient services of gas, water, and electricity, and in disposing of liquid and gaseous waste, require careful consideration and building planning. In the past, because of the special nature of the work carried on in these laboratories, use has often been made of temporary buildings of steel or frame construction. In some cases, equipment has been erected outdoors adjacent to a permanent building from which the services can be supplied. The convenience and economy of having the equipment in a permanent building, however, often justify including a pilot plant laboratory in the building plans.

In all chemical engineering laboratories space for tall equipment should be provided. Experimental distillation columns, evaporators, barometric condensers, and extraction columns require head-room of from 30 to 80 feet. The floor area required for such equipment is usually not great and maximum utilization is desirable for economic reasons. Very tall columns and piping for gravity flow can often be installed in wells or through removable panels on several floors. These laboratories are often constructed with a large bay to provide for a crane for moving heavy equipment. In some cases, balconies surrounding the bay are provided at each floor level, so that tall equipment can be constructed either through floor grilles or adjacent to the columns supporting the balconies. Erection of tall equipment in the bay has two undesirable features; it obstructs the bay so that it can not be used for other purposes and sometimes prevents the full use of the crane. Furthermore, in order to provide convenient operating levels it is often necessary to construct temporary scaffolding or ladders around the equipment. These objections can be overcome by having a narrow bay and erecting all of the equipment through the balconies. Maximum convenience is achieved by using removable beams and grille floors in the balconies to permit erection of equipment with the overhead crane. The main floor should preferably be at ground level, so that trucks may be driven into the laboratory.

Consistent with the trend toward low operating levels in industrial plant construction, the balcony floors should be constructed as mezzanines with floor-to-floor height of 8 to 9 feet for convenience in operating the equipment. Stairs should be placed for easy access to all parts of the balconies.

The features of three of the laboratories in the new chemical engineering laboratory at the University of Illinois are described below. The buildings were designed by the architectural firm of Graham, Anderson, Probst and White, Inc.

UNIT OPERATIONS LABORATORY

This laboratory, shown in figure IV.100 occupies three full floors in the building with a head-room of 38 feet overall. The main floors of the building are at elevations of 13½', 27', 40', 53', and 66' above the ground floor. The mezzanines are located at 9', 18', and 27', so that an extra floor in the laboratory is obtained. The room itself is 57'9" by 56'0" in overall dimensions. The four center columns are 22 feet apart and the cantilevered balconies extend five feet beyond the columns. This leaves a relatively narrow bay of 12 feet between the balconies. Open steel grille floor is used on the overhanging section of the balconies. All of the tall equipment is constructed through these grilles and supported from the main columns or from the cantilever beams. The outside beams may be removed so that heavy equipment may be swung into position by the crane.

The total floor area of the laboratory, including the main floor and the three balconies, is 13,500 square feet. The floor on each balcony between the columns and the walls is pitched to large cross drains so that no water may stand on any floor. There are also three large drains in the main floor, and two drains under the balcony covered with steel grilles. The tall equipment is constructed on these grilles so that water and leakage from the equipment will not run on to the floor. Service lines are located on each of the free standing columns as well as next to the columns in the walls. These include a 2 inch cold water line with valve taps at each floor level, ¾ inch air line, ¾ inch vacuum line, ¾ inch hot water line, 2-inch high pressure steam line, 3 inch medium pressure steam line, 120 volt single phase with duplex outlets of 30 amperes capacity, and 208 volt, 3-phase with 60 amperes capacity outlets at each floor level. There is also a DC panel with convenient outlets on one wall. The estimated maximum requirements for steam and water at any location in this laboratory are 3,000 pounds per hour of medium pressure steam, 1,000 pounds per hour of high pressure steam, and 200 gallons per minute of cold water.

In order to remove gases used or generated in large quantities in the Unit Operations Laboratory two stacks, one on each side of the room, run through to the roof level. These are provided with three 16 inch tile lined flues with openings on each operating level.

Compressors and high capacity blowers to provide air for the various pieces of experimental equipment are located in an acousticized room adjacent to the unit operations laboratory. These machines include a 75 hp 300 cubic feet/minute Sullivan Air Compressor to provide air at 125 pounds per square inch pressure; a 2,000 cubic feet/minute Buffalo blower to provide air at 25 inches; a 5000 cubic feet/minute blower to provide air at 6 inches; a 200 cubic feet/minute Roots-Connersville Compressor to provide air at 7 pounds/square inch.

Shops and store rooms are conveniently located near the laboratory. There is an elevator serving all the floors and mezzanines at one end of the laboratory. The crane is a Northern Engineering "Hi-Lift," two-ton, electrically controlled and operated hoist. A large overhead door is located at one end of the laboratory.

PILOT PLANT LABORATORY

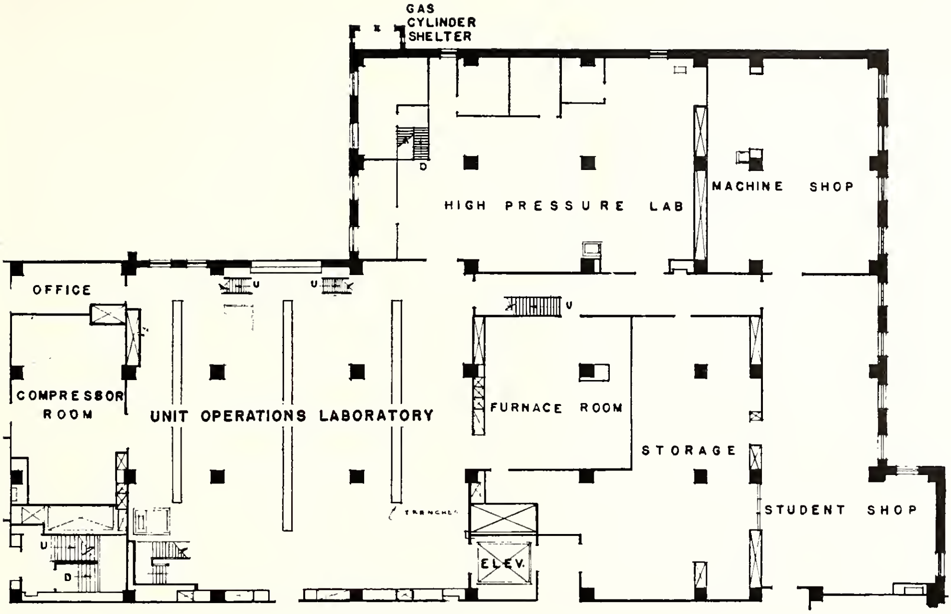
The pilot plant, or process development laboratory, is located on the fourth and fifth floors of the building, immediately above the unit operations laboratory. By using two floors, use has been made here also of small mezzanines to provide tall head-room with low operating levels in a part of the laboratory. The mezzanines, the floors of which are made entirely of steel grille, are constructed at elevations of 9 and 18 feet above the lower floor. The total laboratory floor area is 2600 square feet, and an additional 200 square feet is available on the mezzanine floor. One of the two stacks that are adjacent to the unit operations laboratory passes through this laboratory so that large quantities of gases can be discharged into the air.

The services, which are located on each main floor and on the two mezzanines, consist of a 2-inch water line, ¾ inch air, gas, and vacuum lines, 2 inch high pressure steam line, and 3 inch medium pressure steam line. Electrical services consist of 110 volt single-phase and 208 volt three-phase lines. A panel board erected on the lower floor contains four temperature controllers, one six point temperature recorder, and one flow recorder, connected through conduits to outlets on the mezzanines and the main floors. Adjacent to the laboratory is a small room equipped with the usual chemical laboratory facilities. This is used for control analyses in the operation of the pilot plant equipment.

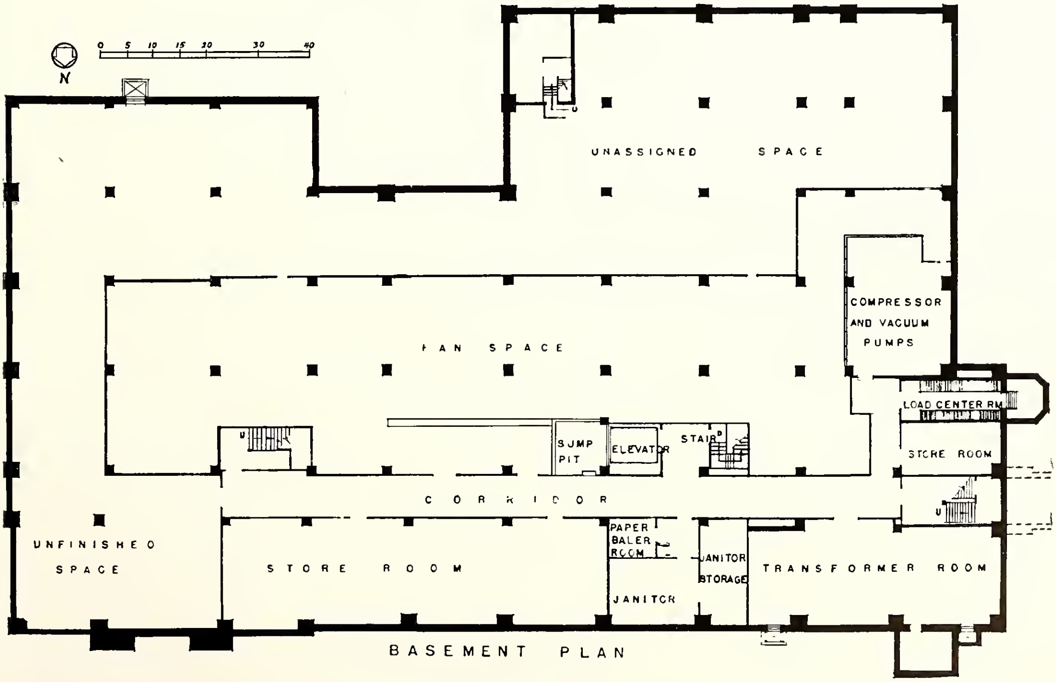
There is an opening 4'0" by 8'0" with removable steel plates in each of the main floors of the pilot plant laboratory and each of the balconies of the unit operations laboratory immediately below. This provides a space for extra tall equipment up to 79 feet in height, and also a convenient duct through which piping may be carried from overhead tanks to each floor of these laboratories.

UNIT PROCESS, OR PROJECTS LABORATORY

This laboratory is located on the second and third floors adjacent to the unit operations laboratory. It provides facilities for undergraduate training in the operation of process equipment, such as nitrators, sulfonators, chlorinators, extractors, etc. A packed distillation column with fifty equivalent plates is also available for student operation. The laboratory is used for project work in which individual students are assigned the types of projects likely to be encountered in the chemical industry. Consequently, much space is allotted to equipment to be designed and built by the students themselves. Here again use is made of small mezzanines located at the 9 and 18 foot levels between and above the main floors. The floors of the mezzanine are made entirely of steel grille which can be removed or cut for tall head-room equipment.

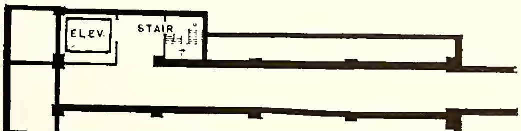


FIRST FLOOR PLAN



BASEMENT PLAN

Figures IV.100, 101 and 102 Sub-basement, basement and first floor plans, East Chemistry Building, University of Illinois, Urbana, Illinois (see also figures IV.104, 105, 106 and 107).



SUB-BASEMENT

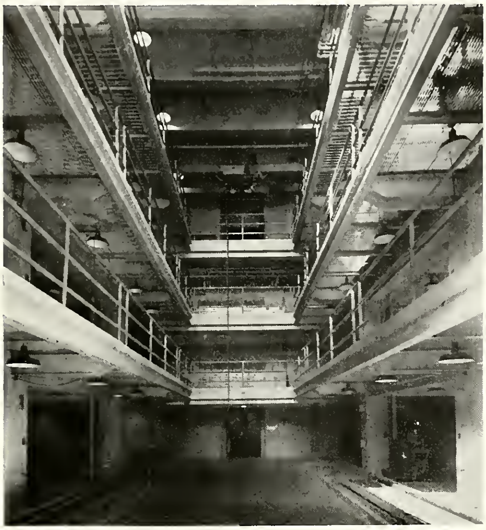


Figure IV.103 Unit Operations Laboratory, University of Illinois, showing the crane bay, mezzanines, and overhanging balconies.

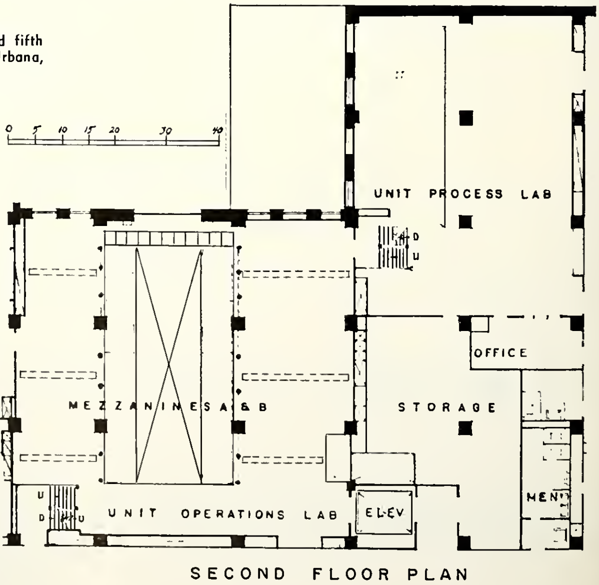
On each main floor of the laboratory there are three chemistry tables of the usual type and two heavy pipe racks designed to support equipment weighing 1,000 pounds, or more. Another pipe rack extends through the mezzanines to the ceiling of the third floor. Thus it can be used from any of the four levels for construction and operation of equipment. These racks are built of 2 inch standard steel pipe with welded construction, and are drilled at 6 inch intervals in the horizontal and vertical directions, alternately, to take ½ inch rods for supports. They are fully serviced with water, gas, electricity, air, and vacuum. In addition, each pipe rack has a duplex set of thermocouple connections and a special 110 volt AC outlet which connects through conduits to panel boards located on each of the main floors. These panel boards contain temperature recorders and controllers so it is possible to connect the thermocouple and control circuits directly to small scale equipment for temperature control and recording.

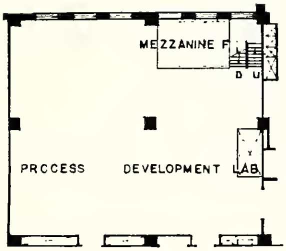
A part of each of the main floors in this laboratory is sloped to large drains. Here the small process equipment will be constructed. The rest of the floor is covered with asphalt tile. The area available on the two main floors of the projects laboratory is 4320 square feet. Each of the rooms is 40′ by 54′. The two mezzanines in this laboratory are 13′ by 17′.

A stairway connects all of the mezzanines and main floors in both the unit operations laboratory and projects laboratory with six exit levels in three floor heights. This stairway leads to a corridor connected with the shops and storerooms used by the chemical engineering division.

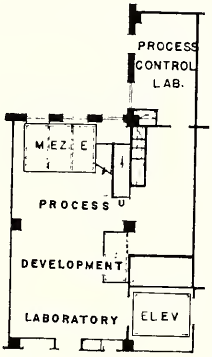
In making plans for these laboratories it was expected that a senior class of about 150 students in chemical engineering would be taking the courses in the unit operations and projects laboratories. Additional rooms in the building are provided for classrooms, and offices and research laboratories for staff and graduate students.

Figures IV.104, 105, 106 and 107 First, second, third, fourth and fifth floor plans, East Chemistry Building, University of Illinois, Urbana, Illinois (see also figures IV.100, 101 and 102).





FIFTH FLOOR PLAN



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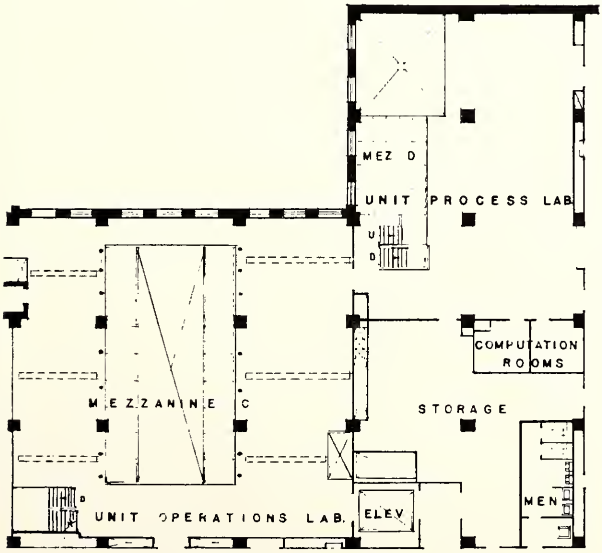

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INDEX

A

ABBOTT LABORATORIES 173
Acoustic laboratories 209, 296
  services 72
ADAMS, C. S. v, *80*, 113
ADELBERGER, E. G. 258
Air conditioning 198, 358, 369
  for physical measurements 205
ALBER, H. K. 188
ALLEGHENY-LUDLUM STEEL CORP. 178
ALUMINUM COMPANY OF AMERICA 164
AMERICAN BRASS CO. 165
AMERICAN INSTRUMENT CO. 247
Analytical control, laboratories 154
  Merck & Co., Inc. 182
Analytical laboratories, teaching *100*, 304
ANHORN, V. J. 255
Animal cages 199
  rooms 195
ANTIOCH COLLEGE 80
Architect, role 3
ARNOLD, E. A. 133
ARNOLD, L. K. 133
Auditoriums 257, 328, 362
AUTOCLAVE ENGINEERS, INC. 246, 247

B

BAILAR, JOHN C., JR. v, *95*, 99
Balance rooms 189
BALDWIN LOCOMOTIVE WORKS 247
BARR, W. E. 255
BASSET, J. 241
BATTELLE MEMORIAL INSTITUTE 211, 241, *306*
BELL TELEPHONE LABORATORIES 145, 203, 209, 250, *336*
BELLUSCHI, PIETRO 298
BENSON, H. K. 133
Biochemical laboratories 113
BLAW-KNOX CO. 246
BOE, C. F. 246
BOLT, R. O. 244, 249
BOOMER, E. H. 246
BOOS, R. N. 188
BOYD, G. E. 227
BRAY, J. L. 133
BRICKWEDDE, F. G. 213
BRIDGMAN, P. W. 241
BRINKER, W. E. v
Building committee, architect's role *4*
Buildings, general science 89
BUREAU OF MINES, pilot plant laboratories 377

C

Cabinetwork, metal 20
  standard designs 21, 22, 23
  wood and metal 20, 106, 115
Cafeterias 258, 362
CALDER, RALPH R. 90
CALDWELL, W. F. 247
CANTRIL, S. T. 226
CARBIDE & CARBON CHEMICALS CORP. 243, 246
CARMICHAEL, DAN A. 309
CARPENTER, CHARLES P. 195
CASE INSTITUTE OF TECHNOLOGY 241
CASE, LEE O. 109
Cases, display and storage 34, 88
Ceilings, construction 9, 318, 348, 356
CHAMPLIN, L. 125
Chemical engineering laboratories 86, *122*, 289, 372
CHEMICAL FOUNDATION iv
CHRISTMAN, A. A. 113
CLARK, E. L. 246, 249
CLARKE, B. L. 182
CLOSE, P. D. 230
Coat rooms 105
Cold rooms 119
COLEMAN, H. S. v, *316*
Compressed air 39
COMPTON, K. G. 250
Conference rooms 257, 328
CONNOLA, D. P. 201
Constant-temperature-humidity rooms 119, *228*, 327
Construction materials, interior 5
CONTINENTAL OIL CO. 168
Cooling pans 34
COPPOCK, WILLIAM H. 302
CORNELL, D. H. 3, *364*
CORNELL UNIVERSITY 122, 128
CORNING GLASS WORKS 159
CORN PRODUCTS REFINING CO. 260
COX, J. L. 246
COYLE, G. L. iii
CROSBY STEAM GAGE CO. 247
Cryogenic laboratories 213, 296

D

DANA, A. W. 258
Darkrooms 204
DARST, OTTO C. 307
DAUBEN, W. J. 227
DENNIS, L. M. iii
Desks, laboratory 327, 332
Distilled and deionized water 39
DONIGER, A. S. 182
Doors and trim 12, 197, 262, 280, 319
DOW CHEMICAL CO. 177, 207, 210
DOWSWELL, H. R. 77
DRAKE UNIVERSITY LABORATORIES 302
DUNLAP, M. E. 228
Duplicating service 256
DUPONT RESEARCH CENTER 138

E

EAGEN, J. H. 58
EASTMAN KODAK CO. 165
EDWARDS, J. W. 227
Electric power *58*, 322
  direct current 60
Electrical measurements laboratories 211
Electrochemical laboratories 250
Electron diffraction laboratories 206
  microscope laboratories 206
Electronic laboratories 211
Equipment, high-pressure 244
  pilot plant 268
ERNST, R. C. v, *134*
ESSO RESEARCH CENTER LABORATORIES 142, 146, *352*
EVANS, R. D. 226
EVANS, R. O. 226

F

Facilities, industrial research 254
FAITH, W. L. 260
FARRELL, M. A. 196
FAWCETT, H. H. 73
Fire alarm system 362
FIRESTONE RESEARCH LABORATORIES 84, 147
FITZPATRICK, T. K. 133
Fixtures, service 35
Floor surfacings 8, 71, 105, 196, 261, 318, 348, 356
Floors, construction and materials 7, 261, 348, 355
FOREST PRODUCTS LABORATORY 228
Fume hoods 31, 61, 72, 326
  radioisotope 218
  standard designs 24, 25
Furniture, laboratory *14*, 71, 78, 96, 100, 106, 115, 185, 324, 348, 371
  radioisotope laboratory 218

G

GALTSOFF, P. S. 201
GARDEN, N. B. 227
Gas 40
Gases, special 41
GENERAL ANILINE & FILM CORP. 280
General chemistry laboratories *95*, 295, 304
GENERAL ELECTRIC CO. 46, 52, 77, 143
GENERAL MILLS, INC. 159
General science building 89
  laboratories 84, 89
GLASCOTE PRODUCTS, INC. 246
Glass washing 120
GLENDENIN, L. E. 226
GLIDDEN CO. 166
GOLDEN, P. L. 246, 249
GOOCH, D. B. 248
GOODRICH CHEMICAL CO., B. F. 177
GOODRICH RESEARCH CENTER, B. F. 3, 48, 55, 56, 203, 206, 211, 243, *364*
GRAHAM, ANDERSON, PROBST & WHITE, INC. 383
GRANETT, P. 201
GRANITE CITY STEEL CO. 180
GREENWALD, H. P. 377
GUILLIEN, ROBERT 213
GULF RESEARCH & DEVELOPMENT CO. 254

H

HAHN, P. F. 227
HAINES, CHARLES S. 336
HAMOR, W. A. v

INDEX

Hangers, wall 291, 320, 349
HANSON, E. S. 249
HANSON, VAN WINKLE, MUNNING CO. 252
HARAND, J. 188
Hardware, builder's 13
HARTZELL, A. 201
HAWKINS, MYRON B. 214
HAYNES, H. L. 201
HAZARD, F. O. 196
HEINZ CO., H. J. 159
HEMEON, W. C. L. v, *61*
HENDERSON, R. W. 254
HENNY, G. C. 226
HENRIQUES, F. C., JR. 227
HENSHAW, P. S. 226
HERCULES POWDER CO. 248
High-pressure equipment 244
    laboratories 72, *241*, 375
HNOT, W. R. 352
HOFFMAN & CRUMPTON 58, 316
Hood, "Mathews" 98
Hoods, air-conditioned laboratories 33, 65, 331, 370
    canopy 33, 67
    fume 31, 61, 72, 326
        air velocities 31, 64, 314, 326
        standard design 24, 25
    perchloric acid 32
    ventilation 62
HOOVER, C. R. iii, 64
Hot plates 34
HOWARD, FRANK 139
HUBBARD, D. O. 133
"Hubbellite" floors 196
HUDDLESTON, E. T. 79
HUFF, C. E. 245
HUNT, FRANKLIN P. 204
HURD, CHARLES D. 102, *105*
HUTCHINSON, M. 201

I

ILLINOIS INSTITUTE OF TECHNOLOGY LABORATORIES 275
INDUSTRIAL HYGIENE FOUNDATION 61
INSTITUTE OF PAPER CHEMISTRY 75
Instrument and machine shop 255
    calibration laboratories 212
Interior arrangements, industrial laboratories 149
    teaching laboratories 80
IOWA STATE COLLEGE 111
ISENBURGER, HERBERT R. 209

J

JANSSEN & COCKEN 316
JASPER, T. M. 246
JENKINS, EDWARD M. v, *5*, *343*
JOHNS-MANVILLE research center 5, 203, *343*
JOHNSTON, HERRICK J. 213
JOHNSTONE, H. F. 383
JOYCE, R. M. 244, 249

K

KETTERING science building 83
KILPATRICK, MARTIN 275
KLUG, HAROLD P. 202
KOHMAN, G. T. v
KRANICH, W. L. 124

L

Laboratories, acoustic 209, 296
    analytical chemistry *100*, 304
    analytical control 154
        Merck & Co., Inc. 182
    animal 195
    biochemical 113
    chemical engineering 86, *122*, 289, 372
    constant-temperature-humidity 119, 228, 327
    cryogenic 213, 296
    electrical measurements 211
    electrochemical 250
    electron diffraction 206
        microscope 206
    electronic 211
Laboratories, general chemistry *95*, 295, 304
    general science 84, 89
    high-pressure 72, *241*, 375
    industrial, analytical control 154
        auxiliary facilities 254
        interior arrangement 149
        location and design 139
        physical measurements 202
    instrument calibration 212
    metallographic 36, *134*
    metallurgical *191*, 289, 309
    microanalytical 188
    organic chemistry *105*, 304
    physical and electrochemical *109*, 293
        measurements 202
        testing 211, 290
    physics 294
    pilot plant *260*, 333, 350, 377, 383
    radiobiochemical 198
    radioisotope 214
    teaching, design and construction 75
        interior arrangement 80
    windowless 50, 81, 150, 368
    x-ray 72
Laboratory desks 327, 332
    furniture *14*, 71, 78, *96*, 100, 106, 115, 185, 324, 348, 371
    plumbing *37*, 322
    tables 15
        definition 15
        island arrangement 27
    ventilation 61
LAWRENCE, G. C. 226
Lecture rooms 78, 86, 287
LEWIS, HARRY F. v, *75*, 113
LEWIS, W. B. 227
LEVY, H. A. 227
LIBBY, W. F. 216, 226
Library 77, 87, 254, 288, 362, 372
Lighting, emergency 59, 382
    industrial inspection 56
    laboratory *46*, 73, 323
    systems, types 51
Location and general design, industrial laboratories 139
LUTZ, F. E. 201

M

Machine and instrument shop 255
MacNEVIN, W. M. 103
MALLMANN, W. L. 196
MANUEL, W. A. 89
MARSHALL COLLEGE 91
MARVIN, G. G. 102
MASSACHUSETTS INSTITUTE OF TECHNOLOGY 102
Mass spectrometry 209
Materials, interior construction 5
MATHEWS, J. H. 98
MATTERN, L. W. iii
MEEHAN, E. J. 100
MEIGS, D. P. 246
MELLON INSTITUTE LABORATORIES 61, 195, 202, 211, *316*
MERCK & CO., INC. 119, 182
Metallographic laboratories 36, *134*
Metallurgical laboratories *191*, 289, 309
Microanalytical laboratories 188
MILLER, EDGAR 280
Module 365
    considerations governing 336
    size 82, 149, 314, 317, 345
MORGAN, C. W. 226
MORGAN, G. W. 215, 226
MORGAN, KARL Z. 226
MORY, A. V. H. iv
MOTLEY, J. G. 202
MURPHY, T. S. 245

N

NATIONAL RESEARCH COUNCIL COMMITTEE iii
NATIONAL SAFETY COUNCIL 69
NAVAL RESEARCH LABORATORY 112
NEEDHAM, J. G. 201
NEWITT, D. M. 241
NEW YORK UNIVERSITY 191
NIER, A. O. C. 227
NORRIS, W. P. 198, 227
NORTHWESTERN TECHNOLOGICAL INSTITUTE LABORATORIES 280
NORTHWESTERN UNIVERSITY 96, 97, 105, 127

O

Offices and laboratories 78, 87, 151, 372
OGG, C. L. 189
OHIO STATE UNIVERSITY 97
OHIO WESLEYAN UNIVERSITY 89
Optical spectroscopy 210
Organic chemistry laboratories *105*, 304
OVERBECK, C. J. 226

P

Paints 13
PARKE-DAVIS CO. 173
PARKER, H. M. 226
Partitions, glazed tile 318
    movable 10, 84, 132, 152, 345, 357

PERRY, JOHN H. 73, 244, 246
PETERSON, A. 201
Physical and electrochemical laboratories *109*, 293
  measurements, industrial laboratories 202
  testing laboratories 211, 290
Physics laboratories 294
Pilot plant equipment 268
  laboratories *260*, 333, 350, *377*, *383*
Piping, service, sizes 44
PITTSBURGH PLATE GLASS CO. 168
Plumbing *37*, 322
POULTER, T. C. 247
PRACK & PRACK 377
PRATT & WHITNEY DIVISION, UNITED AIRCRAFT CORP. 156
PRICE, CHESTER 138
PRICE, DAVID J. 330

Q

QUIMBY, E. H. 226

R

RACE, H. H. 47
Radiobiochemical laboratories 198
Radiography, industrial 208
Radioisotope fume hoods 218
  laboratories 214
  laboratory furniture 218
REED COLLEGE 74, 76, *298*
Refrigeration 42
REGIONAL LABORATORIES, DEPT. AGRICULTURE 119, *330*
REID, JAMES C. 227
REIMAN, STANLEY P. 227
RESSELS, W. J. 249
RHODES, F. H. 133
RICE, C. N. 227
ROCHESTER INSTITUTE OF TECHNOLOGY 53

S

SAARINEN, SAARINEN, AND ASSOCIATES 302
SACKTOR, B. 201
Safety precautions 69, 107, 199, 328, 362, 375, 381
SAPIRIE, S. R. v
SAVAGE, R. L. 241
SCHMIDT, L. D. 91
SCHMITZ, C. G. 133
SCHREIBER, A. P. 227
SCHWOB, CLAUDE R. 227
SCIENTIFIC APPARATUS MAKERS ASSOCIATION *14*, *154*
SCOTT, A. F. 298
SCUDDER, C. M. 246
SEAGRAM & SONS, JOSEPH E., INC. 158
Service fixtures 35
  piping color code 45, 297
    sizes 44
Services, methods of distribution 43, 151, 320, 340, 347
  pilot plant 265, 379
  relation to floors, walls and ceilings 6
SHARP & DOHME, INC. 175
Shelving and shelf brackets 325, 349
SHEPPARD, G. W. 227
SHERWIN, CARL P. 113
SHOUB, EARLE P. 377
SHREVE, LAMB AND HARMON 343
SHREVE, R. N. 133
SHUMAN, L. 230
SINGER, G. 226
Sinks and troughs 28, 325
Site check list 140
  selection 75, 139
Soapstone 17
SOCONY VACUUM OIL CO. 170
SOUTHERN METHODIST UNIVERSITY 92
SPEDDING, F. H. 111
STANDARD OIL CO. (INDIANA) 246
STANDARD OIL DEVELOPMENT CO. 139, 352
STANTON, WILLIAM M. 3, 364
Steam baths 34
STEVENS, H. N. 48
STEYERMARK, A. 189
STILLSON, GORDON H. 254
ST. JOHN, ANCEL 209
Stock rooms 87, 187, 254
STONE, R. S. 226
STONE & WEBSTER ENGINEERING CORP. 37
Storage, flammables 70
STORCH, H. H. 246, 249
STRONG, JOHN 204
STRUTHERS-WELLS CORP. 246
SULLIVAN, W. H. 226
SWAN, J. N. iii
SWARTOUT, J. A. 227
SWEENEY, O. R. 133

T

Tables, laboratory 15
  definition 15
  island arrangement 27
Tabletops 16, 71, 106, 115, 371
  acid-resisting finish 16
  composition 18
  metal 19
  natural stone 17
  soapstone, surface treatment 18
TAFT, R. B. 226
TOMPKINS, E. R. 227
TOMPKINS, P. C. 227
TONGUE, H. 241, 249
Tops, table 16, 71, 106, 115, 371
Traps 35, *42*
TUGMAN, J. L. *46*
TURNER CONSTRUCTION CO. 343

U

UNITED STATES ATOMIC ENERGY COMMISSION, ISOTOPES DIV. 214
UNITED STATES DEPT. AGRICULTURE REGIONAL LABORATORIES 119, *330*
UNITED STATES RUBBER CO. 178
UNIVERSAL ATLAS CEMENT CO. 154
UNIVERSITY OF ILLINOIS 95, 96, *383*
  IOWA 97
  LOUISVILLE 134
  MICHIGAN 91, 109, 113
  MINNESOTA 100
  NEW HAMPSHIRE 79
  WISCONSIN 96, 98

V

Vacuum 40
VAN ATTA, F. A. 69
VAN DER ROHE, MIES 275
VAN HOOK, A. 133
VAN STEENIS, J. 249
Ventilation, laboratory *61*, 320, 322
  radioisotope laboratories 220
VILBRANDT, F. C. 133
VOORHEES, WALKER, FOLEY & SMITH 3, 139, 149, 336, 352

W

WADE, W. B. 125
WALKER, RALPH T. *139*, *149*
Walls, construction and materials 9, 261, 318
WANK, ROLAND A. 3
WASHINGTON STATE COLLEGE 95
Waste disposal, radioisotope laboratories 221
Waste lines 35, 41
Water, distilled and deionized 39
WATERMAN, H. I. 249
WAYNE UNIVERSITY 90
WEBER, H. C. 124, 132
WELCH, P. S. 201
WELCKER, W. A., JR. 306
WESTINGHOUSE ELECTRIC CORP. 163, 251
WHITEHOUSE, A. M. 246, 249
WILLIAMS, G. C. 134
WILLIAMS, V. C. 280
WILSON, WRIGHT D. 227
WINDING, CHARLES C. 122
Windowless laboratories 50, 81, 150, 368
Windows 11, 50, 197, 262, 319, 340, 353
WOLFF, R. T. 196
WORK, HAROLD K. v, *191*

X

X-ray diffraction 208
  laboratories 72

Y

YANKWICH, PETER E. 227
YORK, JOHN EDMUND 37

Z

ZISMAN, W. A. 112

Date Due

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